Normalisation, Evaluation and Verification

of the

NEW ZEALAND HEARING SCREENING TEST.

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ABSTRACT

Presbycusis, or age-related hearing loss, is one of the most common chronic conditions to affect adults. On average individuals wait seven years from the time they notice a hearing impairment to the time they seek help from a hearing professional. This delay may have wide reaching implications for public health in the coming decades, as aging populations become more prevalent and as further research assesses the relationship between hearing loss and mental health conditions such as depression and dementia. The development of the New Zealand Hearing Screening Test (NZHST) aims to fulfil a need for a robust hearing screening test that individuals can access from home. This digit triplet test (DTT) will be particularly valuable for those in rural areas where audiological services are sparse and for those who have mobility issues which restrict attendance at clinical appointments. In order to accommodate as many New Zealanders as possible, the NZHST will have two versions, an internet version and a land-line telephone version; both of which can be delivered into their home in either New Zealand English or Te Reo Māori.

This research is the third instalment in the development of the NZHST. The current research is divided into three parts; the verification of the New Zealand English DTT for the internet version, the pilot study for the Te Reo Māori DTT for the internet version, and the normalisation of the New Zealand English DTT for the telephone version.

In the verification process, 50 individuals with various audiometric thresholds listened to 3 lists of 27 New Zealand English digit triplets, presented in three conditions; binaurally and to each ear separately via an internet interface. In the pilot study, 27 participants with various audiometric thresholds listened to 3 lists of 27 Te Reo Māori digit triplets via a software interface on a laptop computer. The normalisation process involved 10 individuals with normal hearing (average air-conduction pure tone thresholds of ≤ 20 dB HL) listening to 168 New Zealand English digit triplets under two different noise conditions; one as continuous speech noise and the other a noise with spectral and temporal gaps (STG noise) presented via a software interface on a laptop computer. Four conditions of the 168 digits were presented; once to each ear for the continuous noise, and once to each ear for the STG noise.

Significant correlations were found between the binaural DTT and PTA ($R = 0.66$), and between the monaural ear DTT and PTA ($R = 0.73$) for the verification. The binaural DTT had a test sensitivity of 94% and a specificity of 88%. Pilot study correlation between binaural DTT and PTA was $R = 0.61$, and was $R = 0.63$ between monaural DTT and PTA; while the binaural sensitivity (100%) and specificity (100%) of the Te Reo DTT was affected by the very small number of participants with hearing loss ($n = 4$). The normalisation revealed that detection of the digit triplets was easier when STG noise ($L_{mid} = -11.5$ dB SNR, SD = 1.6 dB) was used as a masker, rather than continuous noise ($L_{mid} = -8.9$ dB SNR, SD = 1.4 dB).

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'Begin, be bold, and venture to be wise.'

- Horace

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Chapter 1 INTRODUCTION

Hearing loss is often considered a regrettable but minor consequence of aging (Lin, 2012). This is because the signs of age-related hearing loss can be subtle; no longer hearing the birds outside, missing the high notes of the flute or piccolo in a favourite piece of music, setting the television volume a little louder than in the past, and finding conversation increasingly difficult in group situations. This chapter explores recent literature concerning adult hearing loss; how individuals perceive their hearing impairment (Southall, Gagné, & Jennings, 2010), the impact of hearing loss on their general health (Peelle, Troiani, Grossman, & Wingfield, 2011; Remensnyder, 2011), and reasons why many people with hearing loss do not present at audiology clinics (Gilliver & Hickson, 2011; Meyer & Hickson, 2012). Hearing screening tests are then discussed as they have the potential to be a possible alternative for those unable or reluctant to attend a clinic. Digit Triplet Tests (DTTs) are introduced as hearing screening tests that have been recently adopted at a national level in several European nations. Finally, a commentary on the development of the New Zealand Hearing Screening Test (NZHST) to date will be given, with a preface to the study that will be carried out in this thesis.

1.1 ADULT HEARING LOSS

Worldwide, hearing loss is among the most common chronic conditions to affect adults (Smith et al., 2011). Presbycusis, or age-related hearing loss, is most prevalent with approximately 60-66% of adults aged over 60 years being affected (Gilliver & Hickson, 2011). As aging populations become more common globally, it is likely that greater support and intervention will be required for individuals with hearing loss. However there is often unwillingness to seek professional help and resistance to use any hearing devices that have been prescribed (Meyer & Hickson, 2012). Reasons for this reluctance include perceived stigmatization and the stereotype that only the elderly need hearing aids (Southall, et al., 2010). In spite of these reasons it is important that individuals are aware of the benefits of amplification, as recent research indicates that providing amplification to adults with hearing loss can stall social and cognitive decline (Remensnyder, 2011). This section (1.1) explores the basic physiology of cochlear ageing; the attitudes and concerns held by those diagnosed with hearing loss, and highlights the positive effects of amplification.

1.1.1. THE ANATOMY AND PHYSIOLOGY OF COCHLEAR AGEING

Presbycusis is one form of sensorineural hearing loss. It is defined as a hearing loss caused by anomalies of cochlea, the vestibulocochlear nerve or the central processing centres of the brain (Katz, 2009). Presbycusis (literally *elder hearing*) is characterised by reduced hearing sensitivity; especially in the high frequencies, reduced ability to understand speech in noise, slower central processing of sound and a decreased ability to localize auditory information (Gates & Mills, 2005). Most individuals over the age of 70 will have some hearing impairment; especially those living and working in industrialised societies. In light of this, presbycusis should be viewed as the gradual genetic process of ageing overlaid by the accumulation of years of noise-stress to the auditory system (Gates & Mills, 2005). As it is difficult to differentiate age factors from accumulated noise damage, the terms *age-related hearing loss* and *presbycusis* are used interchangeably in this research.

The auditory system is fundamentally divided into three portions; the outer, middle and inner ear (Figure 1.1). The pinna and external auditory canal form the outer portion of the ear, and direct acoustic sound toward the tympanic membrane (ear drum). At the tympanic membrane this acoustic energy is converted into mechanical vibration which travels through the three small bones of the middle ear. These bones are named the malleus, incus and stapes (collectively known as the ossicular chain) and they perform impedance matching; transferring the sound wave in air through to the fluid-filled cochlea (Gates & Mills, 2005).

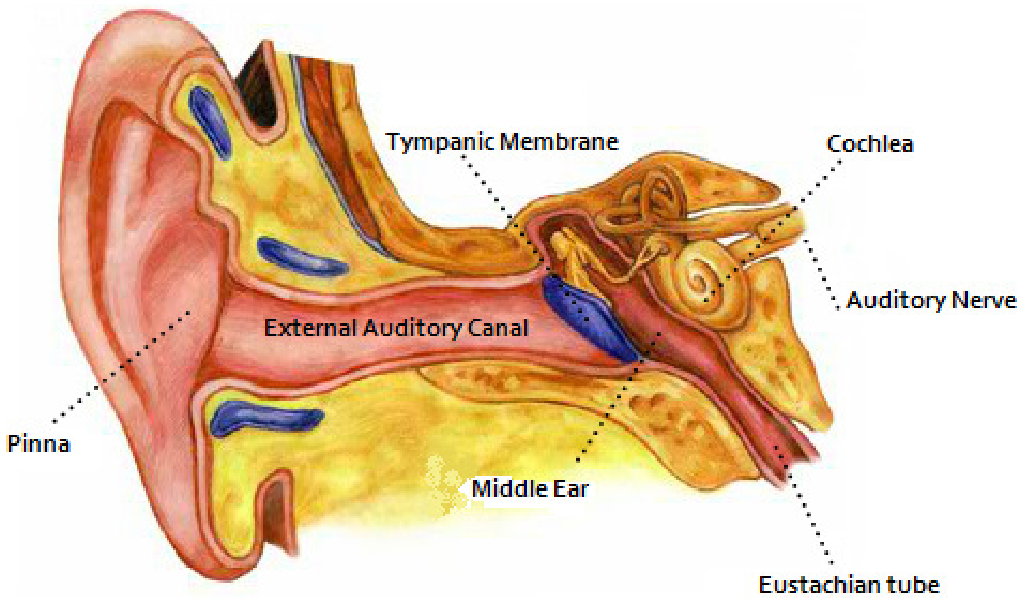

Figure 1.1: The structures of the outer, middle and inner ear.
Illustration adapted from Unitron (2012)

The cochlea is the sensory organ of hearing that converts mechanical pressure waves into auditory nerve impulses which are sent to the brain for processing (Venema, 2006). While the middle ear passively enhances the sound pressure level and is largely unaffected by aging, the cochlea is an active device with non-linear characteristics which is dramatically affected by the aging process (Gates & Mills, 2005).

The name *cochlea* is from the Latin word for snail, chosen for the organ of hearing due to its spiralling structure. The human cochlea is a fluid filled tube around 34 mm in length, which is coiled into a decreasing spiral that winds approximately 2.5 times from the base to apex around the modiolus (Ashmore, 2008). A cross section taken through any portion of the tube reveals that the cochlea is divided into three segments by two membranes (Figure 1.2). The Reissner's membrane and the basilar membrane partition the perilymphatic fluid of the scala vestibuli and scala tympani from the endolymphatic fluid of the scala media. The scala media ends blindly near the apex of the spiral, which allows the scala vestibuli and scala tympani to coalesce at the helicotrema (apex). At the base of the cochlea, two membranous windows open into the middle ear; the oval window which adjoins the footplate of the stapes at the end of the scala vestibuli, and the round window which is the terminus of the scala tympani (Robles & Ruggero, 2001).

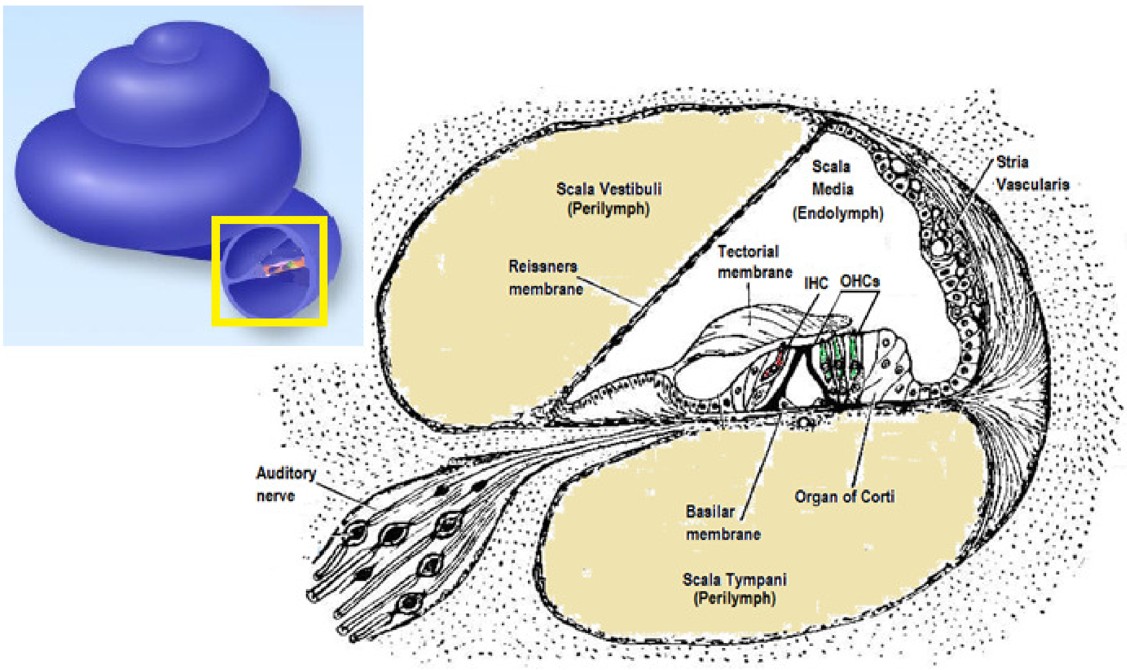

Figure 1.2: Schematic cross-section of a cochlear canal. The sensory Organ of Corti is placed on the basilar membrane within the scala media. Adapted from Rasmussen (1948) and Ashmore (2008).

Scala media contains the outer (OHCs) and inner (IHCs) hair cells of the organ of Corti which convert mechanical fluid vibrations into electrical impulses. The process starts when sound waves are transmitted through the oval window into the scala vestibuli, via the stapes. The sound pressure causes the fluid in the cochlea to move, creating displacement of the basilar membrane beneath the organ of Corti. The position of maximal displacement between the base and apex of the basilar membrane depends on the frequency of the incoming sound signal. This spatial organization of frequency is caused by the mechanical interaction between the fluid dynamics and the stiffness of the basilar membrane; which gets progressively more flexible towards the apical end (Ehret, 1978). This tonotopic arrangement codes for high frequencies at the base of the cochlea, the mid pitches in the central portion of the basilar membrane, and the very lowest frequencies at the apex (Raphael & Altschuler, 2003) (Figure 1.3).

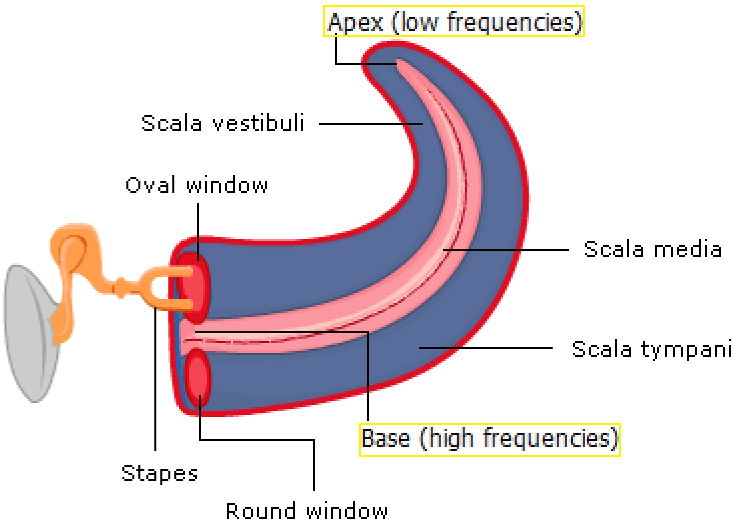

Figure 1.3: Schematic cross-section of the unfurled human cochlea, revealing tonotopic arrangement of frequencies from high (at base) to low (at apex), adapted from e-LearningForHealthcare (2008).

The receptive sensory cells of the auditory system are the OHCs and IHCs (Figure 1.2). These cells are similar in appearance, with clusters of hair-like stereocilia extending into scala media. However the IHCs and OHCs perform different tasks. There are approximately 3,500 IHCs in each human cochlea, these are innervated by the dendrites of the cochlear nerve and perform around 95% of the afferent innervation sent to the brain (Ashmore, 2008). In contrast, OHCs number approximately 11,000 per human cochlea and are arranged in 3 or 4 rows. Although OHCs have sparse (only 5%) afferent innervation, they are motile and their mechanical energy generates an active process that improves cochlear sensitivity by 40-60 dB (Ashmore, 2008). In essence, OHCs have two purposes: (1) they amplify low-level incoming sounds below 40-60 dB SPL, which allows the IHCs to sense them; and (2) they fine-tune the frequency resolution of the cochlea through their mechanical contraction and elongation movements (Venema, 2006).

Damage to either the IHCs or OHCs through aging or noise-trauma can cause loss of these specific functions and culminate in a sensorineural hearing loss. Figure 1.4 displays the effects of aging on the OHCs of rats; note the absence of individual stereocilia bundles for the older rat.

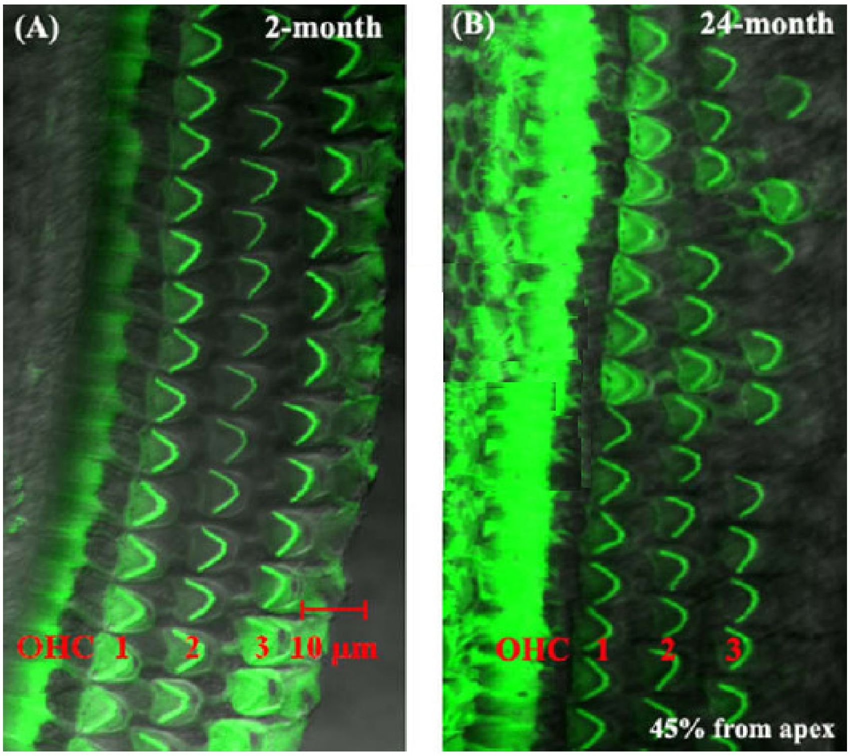

Figure 1.4: Images of the OHC stereocilia of (A) a young rat and (B) an aging rat. The location is approximately 45% from the apex. Adapted from Chen et al. (2008).

Noise-induced hearing loss (NIHL) is caused by repeated exposure to excessive sound. Brief exposure to levels above 85 dB A can cause a temporary threshold shift, while sustained or repeated exposure can cause permanent HC damage (Thorne et al., 2008). Excessive noise causes metabolic exhaustion, whereby glycogen stores are depleted and free radicals are eventually produced (Henderson & Hamernik, 1995). If the intensity is high enough, permanent injury is caused by breaking of cochlear structures, mixing of endolymph and perilymph, apoptosis (cell death) of the HCs and deterioration of the cochlear nerve fibres (Yang, Henderson, Hu, & Nicotera, 2004). According to Kujawa & Liberman (2006), the OHCs are among the most vulnerable structures of the cochlea. The risk of OHC damage is greater at the basal end of the cochlea; the section that is responsible for high frequency sensation and that is closest to the incoming sounds. In clinical practice and medico-legal claims there is often an attempt to divide the total hearing loss of an individual into age-related and noise-induced components, however academics are unsure if hearing loss can be so neatly categorised, and the different methods used for allocating the age and noise contributions are controversial (Kujawa & Liberman, 2006).

1.1.2. Frequency Selectivity and Sensitivity of the Ageing Cochlea

The cochlea HCs amplify and transduce minute fluctuations in atmospheric pressure into a series of action potentials along the auditory nerve. In order for the auditory system to perceive different frequencies, the full range of mechanical fluid vibrations initiate the motion of specific HCs which are encoded by separate neurons of the auditory nerve (Yates, Johnstone, Patuzzi, & Robertson, 1992). This filtering process causes very sharp cochlear tuning; meaning individuals with normal cochlea function can distinguish between sounds that may only differ by several Hz (Yates, et al., 1992). Therefore at any given place along the basilar membrane, the hair cells at a particular location are more responsive to vibrations of a certain frequency. This can be illustrated by a tuning curve for a given basilar membrane location. A tuning curve measures how large an input is required to elicit a given output level as a function of the frequency. Figure 1.5 displays a tuning curve for a location at the basal end of a guinea pig cochlea. At this location the basilar membrane is most sensitive to frequencies of 10.9 kHz because an input of only 10 dB SPL at this frequency is required to produce a velocity of 0.03 mm/s on the membrane. The input level intensity must be greater for other frequencies such as 2 kHz (70 dB SPL input, therefore less sensitive to this frequency) to produce the same velocity at this particular location on the basilar membrane.

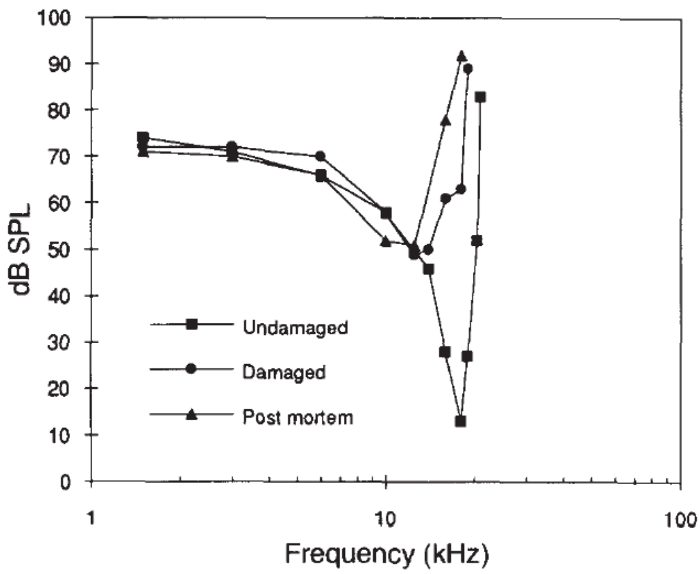

Figure 1.5: Basilar membrane frequency-threshold curve recorded in the basal turn of a guinea pig. Frequency (kHz) is plotted against the intensity (dB SPL) necessary to produce a velocity of 0.03 mm/s on the membrane. Squares indicate measurements of the cochlea in good condition, circles indicate partially damaged cochlea, which shows a decrease in sensitivity and poorer frequency selectivity. At post mortem (triangles) the sensitivity is even poorer and the selectivity is worse (Yates, et al., 1992).

Aging of the OHCs at a particular location along the basilar membrane reduces the active, motor process of those cells. When this occurs the physical properties of the basilar membrane are changed, due to less OHC stretching and shrinking, which reduces the tuning curve to a broader passive peak (Venema, 2006). This means there is less amplification for incoming sounds of those corresponding frequencies. As a result, the peak of the tuning curve becomes less sharp (Figure 1.5).

1.1.3. The impact of Hearing Loss

The consequences of noise-induced and age related hearing loss are permanent and can have a substantial effect on human communication and quality of life (Kujawa & Liberman, 2006). Due to the high prevalence of noise exposure and aging populations, these types of hearing losses have significant public health implications (Lee, Matthews, Dubno, & Mills, 2005). This is particularly important today as there are increasing reports of NIHL occurring earlier in life (Folmer, Greist, & Martin, 2002; Vogel, Brug, Hosli, van der Ploeg, & Raat, 2008).

The magnitude of hearing loss in noise-exposed and aged ears can be quite variable; however there are some general patterns. As people age threshold sensitivity is lost, especially in the higher frequencies, speech discrimination in environments with background noise becomes increasingly challenging (Kujawa & Liberman, 2006). Although these difficulties can impair communication on a regular basis, people who acquire a hearing loss often conceal their difficulties and are reluctant to disclose their hearing loss (Hétu, 1996). This reluctance extends to delays, often of years, in seeking help from a hearing health professional (Southall, et al., 2010). In research it has been reported that this delay can be due to the stigma associated with hearing impairment (Southall, Gagné, & Leroux, 2006).

Stigma is the belief that one possesses an attribute or characteristic that conveys a social identity which is devalued in a particular social context (Crocker, Major, & Steele, 1998). Stigma can affect the initial acknowledgement of hearing loss, the decision to seek help, the style of amplification chosen, and the settings in which the devices are worn (Gates & Mills, 2005; Wallhagen, 2009). Researchers have identified three main types of stigma regarding hearing loss: (a) alterations in self perception; (b) ageism; and (c) vanity (Wallhagen, 2009). Alterations of self perception often cause individuals to contrast themselves with others or their former self (prior to hearing loss); concepts of whole/not whole, able/disabled and smart/cognitively impaired have been noted by researchers in this context. Ageism is related to the negative stereotypes that are associated with older adults, as hearing loss is widely considered a geriatric health problem (Southall, et al., 2010; Wallhagen, 2009). In many societies aging and its associated changes are not valued, therefore individuals with hearing loss may be unwilling to seek help and wear hearing aids for fear of being perceived as elderly, weak or disabled (Kochkin, 2007).

Delays in audiological treatment; be it due to stigma, financial concerns or the insidious onset of hearing loss, can have wider consequences. Hearing loss affects communication with others, so relationships with significant others, co-workers and friends can be substantially affected. Studies have revealed that uncorrected hearing loss can cause reduced quality of life, a greater feeling of isolation and reduced social interaction; which combined lead to feelings of exclusion and in some cases depression (Arlinger, 2003; Thorne, et al., 2008). When the progression of hearing loss is gradual, the individual may not be aware that some sounds have become inaudible. This reduced auditory stimulation can impact intellectual stimulation, and has been known to foster the development of dementia (Arlinger, 2003).

Another affect of untreated hearing loss is late-onset auditory deprivation (Arlinger, Gatehouse, Bentler, Byrne, & Cox, 1996). This occurs when a monaural hearing aid fitting is given to an individual with a bilateral symmetrical loss. After a period of time (as short as one year in some cases), the effects of auditory deprivation can be noticed through poorer speech recognition results for the unaided ear. These effects can be reversed in some people if a binaural fitting is introduced, but there are no obvious factors that can predict the success of recovery (Arlinger, 2003).

As many nations continue to have aging populations, it is important that methods to detect hearing loss and to assist those with hearing impairment are developed and promoted (Meyer et al., 2011). At the present day, 64.6% of Australian adults between 70 and 79 years of age have some hearing impairment (>25 dB averaged over 0.5-4 kHz in one or both ears), the majority of which do not seek help from a hearing professional (Meyer, et al., 2011). Therefore, the impact of untreated hearing loss is not only felt by an individual and their communication partners, but it becomes a public health issue when the consequences could potentially lead to social isolation, depression and dementia for a substantial proportion of the population.

1.2 Hearing Screening

Screening programmes are undertaken in the health sector when the following criteria are met for a particular condition: (a) the negative implications of the condition are sufficient to warrant the costs of screening; (b) there is are appropriate treatments available for those who have the condition; and (c) there is a safe and practical screening tool with sufficient sensitivity and specificity in existence (Yueh, Shapiro, MacLean, & Shekelle, 2003). Age related sensorineural hearing loss fulfils each of these conditions, as it is a the third most prevalent chronic health complaint of older adults (after hypertension and arthritis) and there is evidence to support burdening effects of hearing loss such as functional decline, depression and dementia (Paglialonga, Tognola, & Grandori, 2011; Yueh, et al., 2003). In addition, there are treatments available to manage and mitigate the effects of hearing loss; these include auditory training, environmental accommodations, counselling and hearing aids (Lin, 2012).

Furthermore, there are a variety of tools available to screen for hearing loss. These include self reporting questionnaires such as the Hearing Handicap Inventory for the Elderly-Screening version (HHIE-S), and physiologic measures such as the use of an audioscope (hand-held otoscope/audiometer device that delivers 0.5, 1, 2, 4 kHz pure tones at 25-40 dB) where the patient indicates whether or not they can hear the pure tone stimuli (Yueh, et al., 2003). Although these screening tools are relatively easy to administer and have good sensitivity and specificity, they require the presence of a healthcare professional and usually involve expensive clinical time (Meyer, et al., 2011).

In recent years, innovative, low cost solutions which allow individuals to objectively evaluate their hearing status from home have become available in several countries (Stenfelt, Janssen, Schirkonyer, & Grandori, 2011). There are currently two methods of distributing these hearing tests: (a) via landline telephone networks and (b) via the internet. These tests target the everyday listening difficulties of older adults with hearing loss; including rapid speech, unclear articulation, reverberation and competing speech or noise (Pichora-Fuller & Souza, 2003; Stenfelt, et al., 2011).

1.3 Speech-in-Noise Tests

The reduced ability to hear speech in the presence of background noise is the primary complaint of those with age-related sensorineural hearing loss (George, Festen, & Houtgast, 2006; McArdle, Wilson, & Burks, 2005; Peters, Moore, & Baer, 1998). This is caused by the broadening of auditory tuning curves as HCs become less sensitive or damaged with age, resulting in reduced frequency selectivity, especially in the higher frequencies (Section 1.1.2). Within a setting of background noise, a person with presbycusis will have reduced speech intelligibility. This can be due to several compounding factors. Consonants and vowels have different acoustic cues; consonants are regarded as largely high frequency components, caused by vocal tract constriction, while vowels are of lower formant frequency, are produced by sustained voicing and lack vocal tract constriction (Fogerty, Kewley-Port, & Humes, 2012). Due to the upward spread of masking (whereby low frequency sounds (i.e. background noise) masks higher frequency sounds of lesser amplitude) coupled with the loss of high frequency selectivity in the cochlea, there is reduced intelligibility of consonants in the presence of background noise (Fogerty, et al., 2012).

Speech in noise tests measure an individual’s speech reception threshold (SRT), the signal-to-noise ratio (SNR) that corresponds to 50% intelligibility (Leensen, de Laat, & Dreschler, 2011). In order to determine the SRT these tests are adaptive, measuring over a range of SNRs which are intelligible for those with normal-hearing to those with hearing loss (Soli & Wong, 2008). Individuals with moderate to severe sensorineural hearing loss will have an SRT that is higher than individuals with normal hearing (Peters, et al., 1998). This means that people with hearing loss require the SNR to be higher, in order to achieve the same level of performance as an individual with normal hearing.

A variety of clinically available speech in noise tests have been developed using different speech stimuli, such as sentences, words and digits (McArdle, et al., 2005). The benefit of sentence-length stimuli is that there are multiple target words that can be assessed efficiently, the QuickSIN is one such test that can assess 30 target words in 6 sentences, requiring less than a minute of clinical time (Killion, Niquette, Gundmundsen, Revit, & Benerjee, 2004). However, these tests can have reduced specificity, especially with older populations where cognitive involvement and demands on working memory mean that hearing loss may not be the cause of a poor score (McArdle, et al., 2005). For many clinicians, monosyllabic words and digits are popular speech in noise stimuli as they reduce the influence of working memory and linguistic context on patient performance (McArdle, et al., 2005).

This is important not only for clinical tests, but for screening tests administered remotely; optimum efficiency is required, whereby the highest test accuracy is provided within the least amount of time (Zokoll, Wagener, Brand, Buschermohe, & Kollmeier, 2012). Furthermore, it is important that (a) each list of words or digits within a test are highly comparable, and that (b) the average test results across different languages are very similar (Zokoll, et al., 2012). In the case of hearing screening tests delivered via internet or telephone, digits are preferred as they are inherently closed-set stimuli (0-9 are the only possible answers), meaning agreement between lists of digits is high, especially when all digits are normalised to ensure the speech stimuli are as homogenous as possible (Figure 1.6).

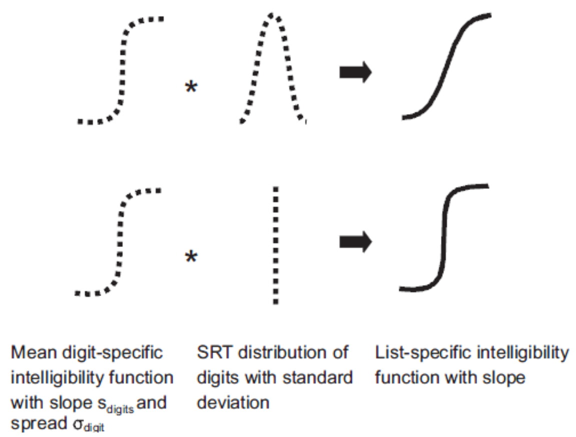

Figure 1.6: Predicting the steepness of the list specific intelligibility function and the distribution of digit-specific SRT values. The intelligibility function of the list is steeper, when the individual digit SRT values are homogenous. Based on probabilistic model of Kollmeier (1990), cited by (Zokoll, et al., 2012).

For use in the home, a computer (with inbuilt speakers or connected earphones) or landline telephone is required. It is likely that the level of ambient noise in the home will be unknown during the test, but by manipulating the ratio of the speech signal to the masking noise (with identical frequency spectra and is passed through the same device), the test is relatively independent from the absolute presentation level and is robust against transmission losses and background noise (Leensen, et al., 2011; Smits, Kapteyn, & Houtgast, 2004). In addition, if presented at the Most Comfortable Loudness (MCL) level, the tests are insensitive to conductive hearing losses (Leensen, et al., 2011; Smits & Houtgast, 2005), providing a screening test for sensorineural hearing loss, which accounts for approximately 90% of hearing losses (Yueh, et al., 2003).

1.3.1. Noise characteristics

Most clinical speech-in-noise tests utilise multi-talker babble as the masker, however research indicates that interrupted noise may be better able to differentiate (a) between listeners with normal hearing and those with hearing loss, and (b) among listeners with different magnitudes of hearing loss (Wilson et al., 2010). According to Peters, et al. (1998), the difference in SRT for people who have normal hearing and those with hearing impairment varies markedly depending on the characteristics of the noise masker. When a speech-shaped noise (same long-term average spectrum as the stimulus) is used the difference is usually around 2 dB to 5 dB SNR. This is a substantial difference in SRT between the two groups; however a greater differentiation can be obtained with interrupted or fluctuating noise (George, et al., 2006; Peters, et al., 1998; Wilson, et al., 2010). Examples of interrupted noise include a single competing talker, a time-reversed talker or amplitude modulated noise (Peters, et al., 1998). With these types of noise the difference in SRT between groups with normal hearing and those with hearing impairment has been found to range from 7 dB to 15 dB, and up to 25 dB with temporally modulated noises (Desloge, Reed, Braida, Perez, & Delhorne, 2010).

The superior performance of individuals with normal hearing arises because they take advantage of the "masking release" (MR) phenomenon (Desloge, et al., 2010; Peters, et al., 1998). MR can be apparent in both temporal and spectral domains. Regardless of whether the interrupted noise is a competing voice or an amplitude-modulated noise, there will be temporal gaps in this masker, through which an individual with sensitive tuning curves will have access to a glimpse of the signal.

The effect of spectral gaps in a masking noise is less recognised (George, et al., 2006). The influence of spectral gaps on speech intelligibility in noise is considered substantial; in that a loss in spectral resolution can result in a reduced MR phenomenon (Healy & Bacon, 2006). However, ter Kers, Festen & Plomp (1993) concluded that many listeners with broadly tuned acoustic filters still had sufficient access to spectral information for speech intelligibility. This could therefore infer that temporal gaps in masking noise may be more effective at segregating the test scores of normal hearing listeners from hearing impaired listeners.

Interrupted (or modulated) noise has been used along with continuous noise in some research (Hewitt, 2008; Wagener & Brand, 2005). Wagener and Brand (2005) compared participant performance on the Oldenburg Sentence Test (A German language test) when presented with a continuous speech noise and when presented with a fluctuating noise. The fluctuating noise generated lower SRT values (-9.9 dB SNR) than the continuous noise (-7.1 dB SNR) for normal hearing participants; however the psychometric functions were shallower. These normal hearing subjects benefited from the MR phenomenon. In contrast, the hearing impaired participants achieved similar SRT scores for both noise types, however the inter-individual standard deviation for the fluctuating noise (SD = 3.0 dB) was twice as large as the stationary noise (SD = 1.3 dB). This meant that some of the hearing-impaired participants were achieving similar SRT scores to normal hearing participants when the fluctuating noise was utilised. Consequently, the researchers recommended the stationary noise as the best masker. Nonetheless, it is important to note that there were some issues concerning the length of the temporal fluctuation in the noise; there were sub-threshold intervals of durations up to two seconds, where participants may have gained access to whole sentences, therefore leading to the variability in SRT and slope. The authors proposed that future testing with fluctuating noise employ briefer temporal gaps (Wagener & Brand, 2005).

An English language sentence test (UK Matrix Sentences) was developed using both a steady speech-shaped noise and a modulated speech-shaped noise (Hewitt, 2008). The researcher noted that modulated noise is likely to have greater face validity, as environmental noise often fluctuates. The modulated noise for the UK Matrix Sentences was generated by superimposing three test sentences on top of each other, with starting points slightly offset. This noise was then reversed to ensure participants could detect little meaning in the masker. The SRT for normal hearing participants when listening to sentences in the steady noise was -8.0 dB (SD = 1.03, psychometric function slope = 12.8%/ dB), and -8.1 dB (SD = 1.36, psychometric function slope = 9.1%/ dB) when listening to sentences embedded in the modulated noise. These results also lead the researcher to recommend steady speech noise as the preferred masker for speech in noise tests (Hewitt, 2008).

In this research both continuous and modulated noise will be used in the normalisation of the New Zealand English DTT for telephone. In order to improve the effectiveness of modulated noise as a masker, the fluctuating noise will be based on the continuous noise and incorporate strictly controlled temporal and spectral gaps. The temporal gaps will be modulated as a rate of 16 Hz, as recommended by Smits & Houtgast (2007), and the spectral gaps will be two equivalent rectangular bandwidths wide according to the formula of Glasberg and Moore (1990).

1.4 Digit Triplet Tests

A DTT consists of three-digit triplet lists, spoken in various levels of background noise to estimate the speech recognition threshold (SRT) of an individual. The listener is asked to enter the digits they hear into the keypad of the telephone or keyboard (e.g. 4-2-5). An "insufficient" or "poor" score on the DTT tells the user that their hearing is below normal, and the software advises them that they may wish to have a further hearing assessment. The hearing status category and any recommendations for further assessment are presented to the individual at the end of the test. Several versions of the digit triplet tests have been produced for different languages; English [Australian, UK and USA] (Golding, Seymour, Dillon, Carter, & Zhou, 2007; Hall, 2006; Phipps, 2007; Wilson & Weakley, 2004), Dutch (Smits, et al., 2004), German (K. C. Wagener, Bräcker, Brand, & Kollmeier, 2006; Zokoll, et al., 2012), Polish (Ozimek, Kutzner, Sek, & Wicher, 2009) and French (Jansen, Luts, Wagener, Frachet, & Wouters, 2010) to date, with publications of the Swedish and Greek versions not yet available (Zokoll, et al., 2012).

The following section discusses the development of digit triplet tests for different languages over the last decade, and leads into the current development of the digit triplet test for the New Zealand Hearing Screening Test.

1.4.1. International DTTs

Seminal research by Miller, Heise, & Lichten (1951) investigated the use of digit stimuli embedded in noise as a measure of speech intelligibility. Rudmin (Rudmin, 1987) noted that 40% of Canadians did not speak English as their first language, and therefore advocated that digit stimuli should be adopted for SRT testing in Canada and other multilingual populations. Digits are among the first words learnt when introduced to a second language; and as SRT stimuli they produce a closed set test. Therefore, Rudmin (1987) believed that digits were more appropriate for SRT testing than open set words or closed set spondees.

The Dutch DTT hearing screening test was the first to be developed for home-based telephone and internet use (Smits, et al., 2004). English [Australian and UK], French, Polish and German versions have been produced in the last decade (Golding, et al., 2007; Hall, 2006; Jansen, et al., 2010; Ozimek, et al., 2009; K. C. Wagener, et al., 2006). All of these DTTs were created to provide a fast and easy screening tool for individuals who speak a particular language.

There are two main measures of test validity and reliability used by researchers when formulating DTTs for various languages. They are measures of (a) sensitivity and specificity, and (b) the slope of speech intelligibility functions (Smits, et al., 2004; Zokoll, et al., 2012). Sensitivity is the proportion of positive diagnoses which are correctly identified by the test (individuals with hearing loss are identified as having hearing loss), while the specificity is the proportion of true negative diagnoses which are correctly identified (individuals without hearing loss are identified as having normal hearing by the test). There is usually a trade off between sensitivity and specificity, which researchers can display graphically as a receiver operating characteristic (ROC) curve (Figure 1.7). The Dutch DTT had high sensitivity (0.91) and specificity (0.93) (Smits, et al., 2004). The authors of the French version noted the importance of high sensitivity and specificity in their review of recent literature, although they omitted these values in their research (Jansen, et al., 2010). The article concerning the Polish version did not mention sensitivity or specificity; however they displayed 13 speech intelligibility functions for various 3-digit combinations in their research (Ozimek, et al., 2009).

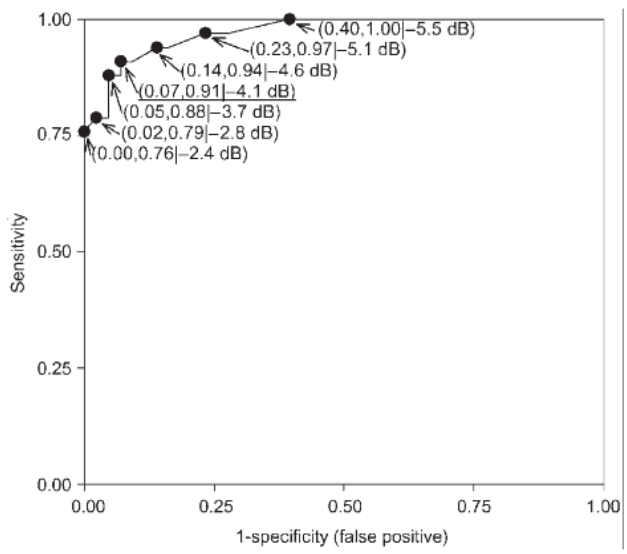

Figure 1.7: Receiver operating Curve (ROC) showing the sensitivity and specificity of the triplet SRT test depending on the cut-off value. The 1-specificity, sensitivity and cut-off values are given in parentheses. The underlined values represent the values chosen as optimal (Smits, et al., 2004).

A steep speech intelligibility function is a second measure of test efficacy. The probability of entering an incorrect digit-triplet into the telephone keypad is denoted by the area above the curve, and the probability of entering the correct digit-triplet is denoted by the area below the curve. Therefore, with a poor SNR (very negative), one would expect to have low speech intelligibility (% correct); while a good SNR (positive or slightly negative) would increase speech intelligibility for the participant (Figure 1.8). To ensure that a screening test has sufficient reliability, the slope of the psychometric function must be as steep as possible (Jansen, et al., 2010). All the researchers that have developed new DTTs in the last decade have included speech intelligibility functions in their publications; these give the reader an immediate visual indication of test validity.

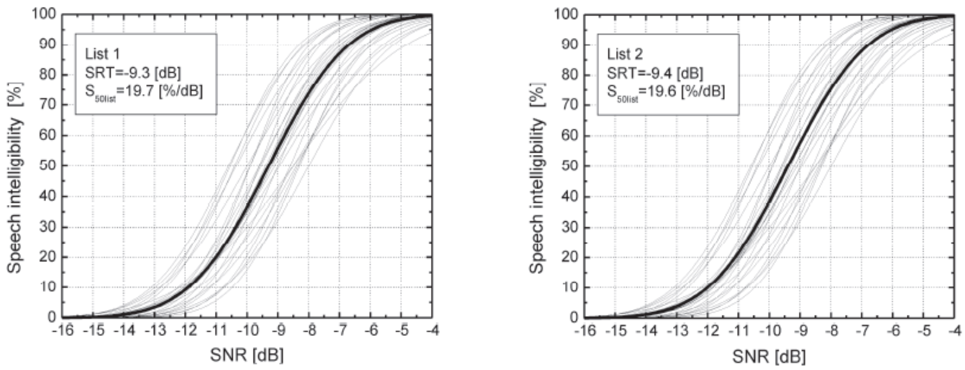

Figure 1.8: Triplet-specific intelligibility functions for the respective digit triplets (thin lines, n=25) and the list-specific intelligibility functions (solid lines, n=1) of the lists. (adapted from Ozimek et al., 2009)

1.4.2. The New Zealand DTT

The creation of the New Zealand Hearing Screening Test (NZHST) aims to give New Zealand adults the opportunity to screen their hearing through access to a speech-in-noise test in either New Zealand English or Te Reo Māori, delivered into their homes via the internet or landline telephone. The internet version will be valuable for those living in rural areas or who have busy lives during working hours, while the telephone DTT will be especially beneficial for those who are less confident with computers or have no access to broadband internet.

The research within this thesis is the third study undertaken to assist in the formation of the NZHST. The first was undertaken by King (2011) who performed the normalisation and pilot study for the New Zealand English internet version. Subsequently, Murray (2012) performed the normalisation for the Te Reo Māori internet version. A schematic diagram of the NZHST creation progress is shown in Figure 1.9.

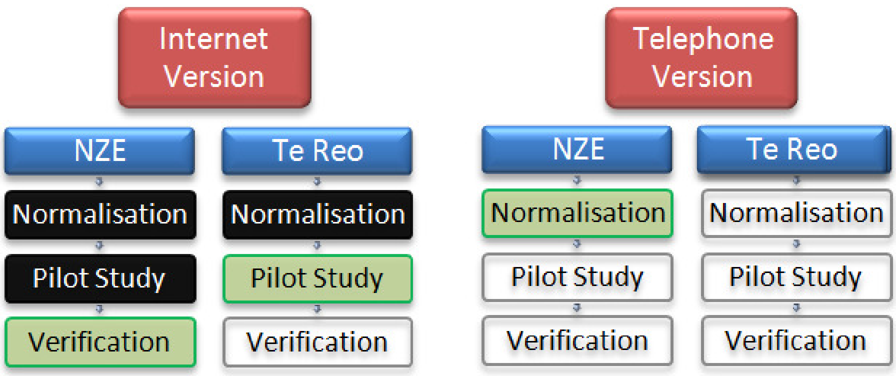

Figure 1.9: Conceptualisation of the creation progress for the NZHST. There are two versions, each with two languages. Completed procedures are coloured black, procedures yet to be undertaken are coloured white, and procedures undertaken in this research are coloured green.

The research of King (2011) included the development of a New Zealand English speech stimulus; this involved the selection of an individual (a 26 year old female) with an authentic and representative New Zealand accent and then the recording of them speaking the digit stimuli. The New Zealand English digits 1-9 (excluding bisyllabic 7 and 0) were used. The speech noise was then created by super-imposing the 24 digit recordings 10,000 times. The digit stimuli with speech noise were then normalised for intensity level and intelligibility function for each digit in each triplet position. For the intelligibility normalisation undertaken by King (2011), 22 participants with normal hearing were required to listen to 168 triplet combinations at different signal to noise ratios (SNR) and enter the digits that they heard into a computer number-pad. The pilot study involved 71 participants listening to the normalised digits, (arranged into lists of 27 digit-triplets) in three listening situations; one delivered binaurally, and then one to each ear separately. This pilot study was to determine the accuracy of the DTT at screening for hearing impairment and delivering an appropriate result. It was also used to establish cut-off values for the three possible categories of hearing ability; "normal", "insufficient" and "poor".

Murray (2012) commenced the development of the Te Reo Māori DTT for the internet version of the NZHST. The recording and processing of the speech stimuli and noise occurred in a similar method to that of the New Zealand English DTT. The Te Reo Māori digits 0-9 (excluding monosyllabic 4) were used. Eight participants were recruited for the digit normalisation procedure, during which they listened to 144 triplets and entered their responses into a computer number-pad. The pilot study in the second phase of Murray's (2012) research was hampered by the difficulty in recruiting participants in the Christchurch area who could speak Te Reo Māori and by the ongoing seismic activity experienced in the Canterbury region during 2011.

This current research aimed to build on the work of King (2011) and Murray (2012), through the verification of the internet version of the New Zealand English DTT, the continuation of the pilot study for the Te Reo Maori DTT, and the normalisation of the telephone version of the New Zealand English DTT. The verification process was undertaken to ensure that the current set up of the DTT was valid for the wider New Zealand English speaking population, and not just the initial pilot study sample. The pilot study for the Te Reo Maori DTT was dependent on persistent participant recruitment throughout the 2012 academic year, due to the small Maori population in Christchurch compared to centres in the North Island of New Zealand. The normalisation process intended to ensure each of the 168 New Zealand English digit triplet recordings had equal intelligibility when directed through the telephone network.

Chapter 2 PART A: VERIFICATION

2.1 METHODOLOGY FOR THE TEST VERIFICATION

This section describes the methods used in the verification of the New Zealand English digit-triplets for the internet version of the New Zealand Hearing Screening Test. The subsections below detail the participant characteristics, the types of instrumentation used and the procedures undertaken during the verification process.

2.1.1. PARTICIPANTS

Fifty-one individuals participated in this verification of the New Zealand English version of the NZHST. They were staff or students of the University of Canterbury, clients of the University of Canterbury Speech and Hearing Clinic, or members of the surrounding Christchurch community. The data from one participant was excluded as they could not complete all three testing conditions, leaving 50 participants from whom DTT results were gathered and analysed. The age and sex distribution of the remaining 50 participants are displayed in Table 2.1. The table reveals 28 females and 22 males participated; with the largest proportion of the females in the 18 to 30 years category and the greatest proportion of males in the ≥ 61 years category.

Table 2.1: The age/sex distribution of the participants for the NZ English test verification.

	Age				
Sex	**18y-30y**	**31y-45y**	**46y-60y**	**≥ 61y**	**Total**
Female	13	2	7	6	28
Male	3	3	5	11	22
Total	16	5	12	17	50

2.1.2. INSTRUMENTATION

This research was undertaken at the Department of Communication Disorders, where the audiological equipment is shared between researchers, students and the University of Canterbury Speech and Hearing Clinic. As such, it was not possible to assess all the participants' pure-tone thresholds in the same room with the same equipment. Two different equipment configurations were used throughout the NZ English version verification and they are described in Table 2.2. A biological calibration of each of these audiometer configurations is performed twice weekly.

Table 2.2: The two audiometer and earphone configurations used to obtain the octave-frequency pure-tone thresholds for each participant in this research.

	Audiometer specifications	Insert earphones	Supra-aural earphones	No. of participants tested using each configuration
Configuration 1	Grason-Stadler GSI 61clinical two-channel audiometer (SN AA051664)	Eartone-3A insert earphones Right (SN 20678) Left (SN 20677)	Telephonics TDH-50P earphones Right (SN C64094) Left (SN C64093)	16 with insert earphones 25 with supra-aural earphones
Configuration 2	Grason-Stadler GSI 61clinical two-channel audiometer (SN AA083951)	Eartone-3A insert earphones Right (SN C70590) Left (SN C70589)	Telephonics THD-50P earphones Right (SN C70588) Left (SN C70587)	7 with insert earphones 2 with supra-aural earphones

The tympanometer used to assess participant middle ear function in this verification study was a Grason-Stadler GSI TympStar Middle Ear Analyzer (SN AL062374).

The speech material used for the New Zealand English version of the New Zealand Hearing Screening Test was a recording of spoken digits embedded in speech noise. The recorded digits were spoken by a 26 year old female whose accent had been analysed and confirmed as New Zealand English (Maclagan & Hay, 2007). She had read several lists of digit triplets, with a carrier phrase i.e. "The digits: one-two-one" using natural intonation. Each of the eight monosyllabic digits of New Zealand English (1 to 9, excluding disyllabic 7) had been said in all three positions in the triplet. These were then split into 24 separate sound files for normalisation and use in the test. Detailed analysis of the recording and normalisation of these digit triplet lists can be found in the thesis of King (2011).

The speech noise used in this research was generated by randomly superimposing the 24 individual digit recordings on top of each other 10, 000 times creating a speech noise file with a spectrum that was almost identical to that of the digits (signal). This similar spectral content means that the signal-to-noise (SNR) of the stimuli would not be altered by filtering at the transducer level (within certain limits), as the signal and noise would be equally filtered if it they passed through a band-limited filter such as a land-line telephone or broadband signal. Further analysis and a power spectra of the signal and noise were provided by King (2011).

The testing was undertaken with two transducer configurations; (a) a SONY VAIO laptop (Processor: Intel® Core ™2 Duo CPU; T6600 @ 2.20 GHz) with Sennheiser HD215 earphones that were coupled to the laptop via a Buddy 6G USB soundcard (InSyncSpeechTechnologies, 2012), and (b) using the in-built HP Realtek High Definition Audio speakers of the same SONY VAIO laptop.

2.1.3. MODIFICATIONS TO THE NZE DIGIT TRIPLET TEST

To maximise the slope of digit lists and therefore the sensitivity of the test, the version of the New Zealand English DTT developed by King featured test lists that had unequal distributions of the digits in each position. In that version, sets of triplets were constructed such that the digit with the highest slope in each position occurred 75% more frequently than the hypothetical average and the digit with the lowest slope occurred 75% less frequently, with the frequencies of the other digits in between. A reviewer of King's thesis raised the possibility that this bias might be detected by participants, and might artificially improve their performance. In light of this, a new set of 8 test lists were created which feature much more equal digit distributions (between 3 and 4 occurrences of each digit in each position per list). A computer-based procedure (O'Beirne, 2012) was used to select triplets to form lists that were homogenous in both digit distribution and in triplet slopes. Across the 8 new lists, each digit now appears between 26 and 28 times in each position, compared to between 7 and 62 times in 10 lists of the previous version. The calculated (i.e. not measured) distribution of the triplet slopes in the new lists is shown in Table 2.3.

Table 2.3: The mean, standard deviation, and range of triplet slopes in each of the new 8 lists.

	List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8	*Mean*	*StDev*	*Max*	*Min*
Mean	15.9 %/dB	16.2 %/dB	15.9 %/dB	16.0 %/dB	15.8 %/dB	16.0 %/dB	16.1 %/dB	15.8 %/dB	*15.9 %/dB*	*0.2 %/dB*	*16.2 %/dB*	*15.8 %/dB*
StDev	2.2 %/dB	2.9 %/dB	2.3 %/dB	2.9 %/dB	3.0 %/dB	3.4 %/dB	3.4 %/dB	2.6 %/dB	*2.8 %/dB*	*0.4 %/dB*	*3.4 %/dB*	*2.3 %/dB*
Max	21.1 %/dB	22.2 %/dB	20.0 %/dB	20.2 %/dB	20.6 %/dB	22.7 %/dB	22.7 %/dB	20.1 %/dB	*21.2 %/dB*	*1.2 %/dB*	*22.7 %/dB*	*20.0 %/dB*
Min	12.3 %/dB	10.7 %/dB	10.7 %/dB	8.5 %/dB	10.9 %/dB	10.2 %/dB	9.4 %/dB	8.4 %/dB	*10.2 %/dB*	*1.3 %/dB*	*12.3 %/dB*	*8.4 %/dB*

In the study by King, the DTT was administered using a modified version of the LabVIEW-based UCAST platform developed by Dr Greg O'Beirne (2006-2013). For the present study, the DTT was administered using a web-based platform developed by Robert Fromont (2011-2012), shown in Figure 2.1.

2.1.4. INTERVIEW AND AUDIOMETRY PROCEDURE

The informal interview and audiometric procedure were undertaken in the sound treated rooms (mean ambient sound level = 29.5 dB A) of the Speech and Hearing Clinic at the Department of Communication Disorders (University of Canterbury, New Zealand) between September and December 2012. Each participant was tested individually at scheduled appointments arranged via email. The appointment began with an unstructured interview where the procedure was explained to the participant and they were asked to sign a consent form with the understanding that their test results would be de-identified and would be destroyed after 5 years. They were also given the opportunity to enter a prize draw to win one of six Westfield Mall vouchers to the value of sixty dollars. The participant was then asked their date of birth and was asked to rate their hearing ability on a scale of 1 to 5 (where 1 was very poor and 5 was excellent).

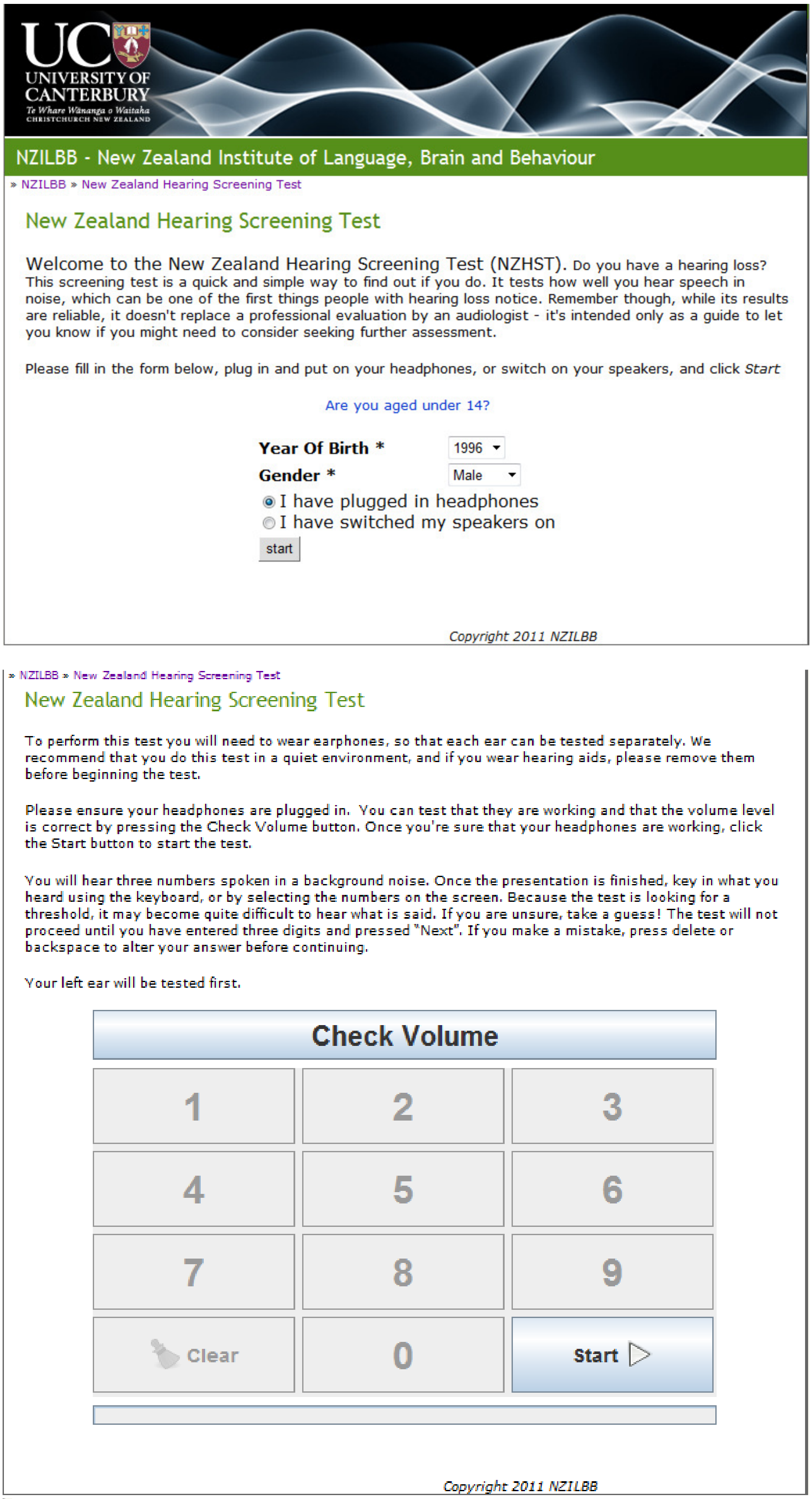

Figure 2.1: The web interface used for the online New Zealand English version (programmed by Robert Fromont).

Otoscopy was performed to assess the health of the external auditory canal and tympanic membrane, and to ensure that if cerumen was present it would not interfere with audiometric testing. The participant then received a diagnostic hearing test using one of the audiometer and earphone configurations displayed in Table 2.2. Pure-tone audiometry was used as the diagnostic hearing test because it is considered the gold standard for assessing hearing sensitivity. The modified Hughson-Westlake method was used for determining pure-tone air conduction thresholds for each ear across the six octave-frequencies; 0.25, 0.5, 1, 2, 4 and 8 kHz (Carhart & Jerger, 1959). Bone conduction thresholds were measured if air conduction thresholds were equal to or greater than 20 dB HL at 0.5, 1, 2 or 4 kHz. Pure-tones were used as stimuli and were presented for 1-2 seconds with varied inter-stimulus intervals of at least 3 seconds. The starting level for presentation at each frequency was 30 dB HL if normal hearing was suspected; or 50 dB HL if a hearing loss was suspected. If no response was elicited at 50 dB HL then the level was increased in increments of 20 dB HL until a response was obtained. A threshold was defined as the lowest level at which a minimum of two responses from three ascending presentations were obtained. These protocols are identical to the audiometry guidelines for adult assessment used by the New Zealand Audiological Society (NZAS, 2012).

Objective measures of tympanic membrane health were then determined via tympanometry, using the Grason-Stadler GSI TympStar tympanometer. This was to identify the presence of any conductive component such as middle ear fluid or tympanic membrane retraction. The DTT is a test for sensorineural hearing loss, so it was important to be aware of any conductive components. A purely conductive hearing loss would not negatively affect DTT performance, but would cause elevated PTA thresholds. The type of tympanogram, the middle ear pressure, static compliance, equivalent ear canal volume and tympanic width were recorded for each ear of every participant.

Each participant had their pure-tone audiometry and tympanometry results explained to them. In cases where a hearing loss was found, information was provided to that participant on listening strategies and available support services or further audiological or medical services.

2.1.5. Digit Triplet Test Procedure

Participants were seated at a laptop for the DTT. A browser window was open at the website of the NZHST for New Zealand English. The participants were told the test would have 3 parts; one part presented binaurally from the laptop speakers, and two parts were presented to either ear under earphones. They were told that for each part they would hear a recording of a woman saying lists of three-digit phrases preceded by a carrier phrase ("The digits") in the presence of a background noise. They were instructed to enter the three-digit phrases into the computer number keypad in the order that they were presented.

Three lists of 27 digit-triplets were presented to each participant; one list presented binaurally from the laptop speakers, and two lists (left ear, then right ear) were presented under earphones. The online software randomly selected 3 of the 8 possible lists for each participant, and the list number was unknown to the researcher until data analysis was performed (Table 2.4). When under earphones for the separate ear lists, the online software always commenced testing with the left ear. From Participant 2 onwards, the researcher alternated the first list presentation between the binaural setting and the earphone (left ear first) setting.

Table 2.4: Presentation order of NZ English DTT lists for the first five participants. Neither the participant nor the researcher (until after the test) knew which lists were presented, as the software randomly selected the lists.

Participant	First Trial	Second Trial	Third Trial
1	Left	Right	Binaural
2	Left	Right	Binaural
3	Binaural	Left	Right
4	Left	Right	Binaural
5	Binaural	Left	Right

The participants were told that the DTT was trying to find the level at which speech was only just perceptible, and were reassured to not be concerned if the digits became increasingly inaudible; they were instructed to just enter what they thought they heard, or if they had no idea then enter the most likely triplet into the number pad and press enter.

To be scored as a correct triplet, all of the digits entered into the keyboard had to be identical in number and sequence to those presented to through the earphones. Participants were not informed that the digits 7 and 0 were omitted, but were told that 0-9 were possible response options.

After completing all 3 lists, the website displayed their results for each listening condition as either “good”, “insufficient” or “poor” based on the cut-offs from the previous pilot study (King, 2011). The participants were encouraged to seek further diagnostic assessment if a hearing loss was discovered, and were thanked for their time. The comprehensive results of each participant were automatically sent from the website to the email address of the primary research supervisor in a comma-separated values (CSV) file.

2.2 Verification Results

This section analyses the participant characteristics and divides them into two groups based on air conduction PTA (0.25 - 8 kHz). The correlation between the participants' DTT scores and PTA thresholds is also quantified. The sensitivity and specificity of the NZ English DTT as a screening test for hearing loss is also described through the use of receiver operating characteristic (ROC) curves; and cut-off DTT values are chosen for the different hearing classifications.

In addition, comparisons will be made between the results of this research and the results obtained by the initial pilot study (King, 2011). As this is a verification of King's (2011) pilot study for the NZ English DTT it is important to observe any differences between the two datasets.

2.2.1. Audiometric Results of Verification

The participant results were divided into two groups on the basis of hearing ability; individuals assigned to Group 1 had normal hearing and individuals assigned to Group 2 had hearing loss (Figure 2.2). Normal hearing was defined as having air-conduction pure tone thresholds of ≤ 20 dB HL for each of the six audiometric octave frequencies (0.25 - 8 kHz) in each ear, or if one or more thresholds exceeded 20 dB HL in one ear but the total PTA (0.25 - 8 kHz) of the better ear was ≤ 20 dB HL.

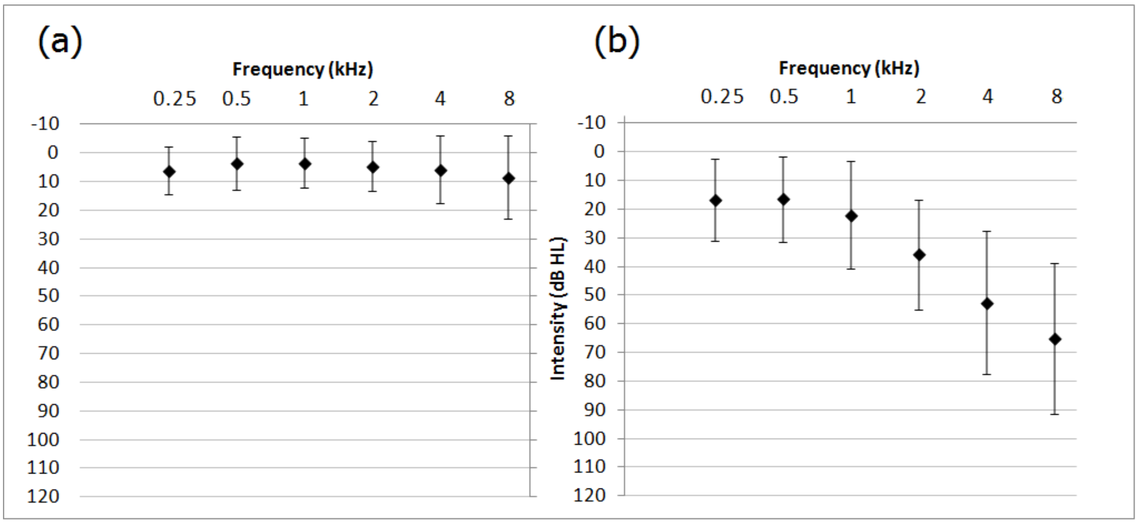

Figure 2.2: Average air-conduction pure tone thresholds for (a) Group 1 (n = 34) and (b) Group 2 (n = 16).

Analysis of the characteristics of each group follows: individuals in Group 1 had normal or essentially normal hearing; 24 females (Mean age = 39.3 years, SD ± 19.8 years, PTA M = 5.7 dB HL, SD ± 9.2 dB HL, DTT threshold M = -10.3 dB SNR, SD ± 1.0 dB), and 10 males (Mean age = 38.0, SD ± 15.8 years, PTA M = 4.6 dB HL, SD ± 11.1 dB HL, DTT threshold M = -10.0

dB SNR, SD ± 1.0 dB). Those in Group 2 had some degree of hearing impairment: 4 females (Mean age = 64.5, SD ± 26.9 years, PTA M = 38.8 dB HL, SD ± 15.0 dB HL, DTT threshold M = -7.0 dB SNR, SD ± 3.9 dB) and 12 males (Mean age= 68.8, SD ± 6.7 years, PTA M = 33.6 dB HL, SD ± 17.9 dB HL, DTT threshold M = -4.98 dB SNR, SD± 3.71dB).

In her pilot study, King (2011) analysed the results of 71 participants and divided them into two groups for the binaural part of her study. There were 62 participants in her normal hearing group and nine participants in her hearing impaired group. Participants were placed in either group based on the average of the thresholds in the better ear at each frequency between 0.25 – 8 kHz.

2.2.2. Analysis of Binaural DTT results

A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between the binaural average of thresholds in the better ear at each frequency (0.25 - 8 kHz) and the binaural triplet test SNR threshold (n= 50). There was a correlation of r = 0.66 between the two variables in this verification study as shown in Figure 2.3.

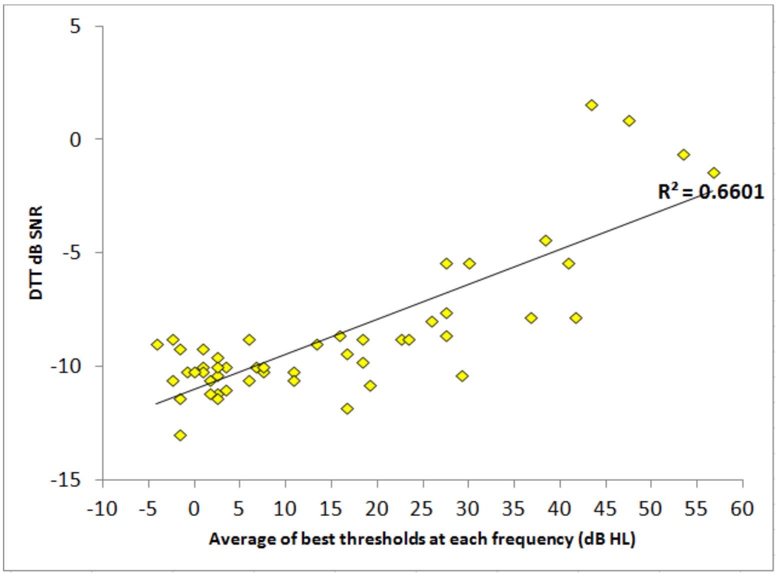

Figure 2.3: Scatterplot and linear regression of the binaural DTT (dB SNR) correlated with the binaural average of the thresholds of the better ear at each frequency (0.25-8 kHz); with regression line and R value.

This correlation is not directly comparable to that of the pilot study by King (2011). The pilot study correlation, using the same variables, gave a significant r value of 0.816 ($p < 0.001$). However there is a fundamental difference between how the binaural data was gathered for the pilot study and for the verification. Participants in the pilot study listened to the binaural stimuli under earphones, while the verification study stimuli for the binaural condition was played through the laptop speakers into a sound treated room (mean ambient noise level = 32.3 dB A). This change in method recognised that not all individuals undertaking the online DTT in a home environment will have access to earphones, and may therefore play the stimuli through their computer speakers.

In order to determine how reliable this binaural DTT is for identifying hearing loss, a receiver operating characteristic (ROC) curve was created. This curve assesses the true positive rate (sensitivity) and false positive rate (1-specificity) of the test. The DTT threshold was used as the index score, while the PTA score was the reference standard. The red point highlighted on the ROC curve in Figure 2.4 reveals the most sensitive relationship between DTT threshold and PTA reference score. At this point the test sensitivity is 94 % and the specificity is 88 % (1-Specificity is 12 %); the cut-off value for 'normal' hearing is -8.8 dB SNR.

Setting the normal hearing cut off at -8.8 dB SNR resulted in 19 participants (6 female, 13 male) receiving an insufficient or poor classification (Figure 2.5 and Table 2.5). This group consisted of 15 correctly identified individuals with better-ear air-conduction PTA thresholds (0.25-8 kHz) of >20 dB HL (True Positive), and four incorrectly identified participants who actually had better-ear PTA thresholds <20 dB HL (False Positive). On closer examination of those four individuals; one had a moderate loss at 4 kHz bilaterally and another had a mild to moderate loss in their right ear. The averaging of the thresholds in the better ear at each frequency (for the PTA threshold) effectively concealed any high frequency hearing loss or asymmetry. The remaining two participants had all six octave frequency thresholds at levels ≤20 dB HL in the better ear.

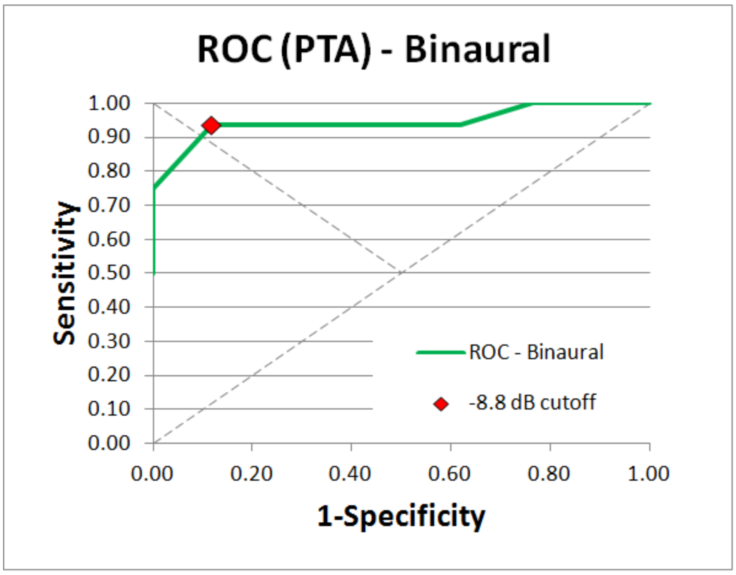

Figure 2.4: Receiver-operating characteristic curve for binaural presentation of the NZ English DTT.

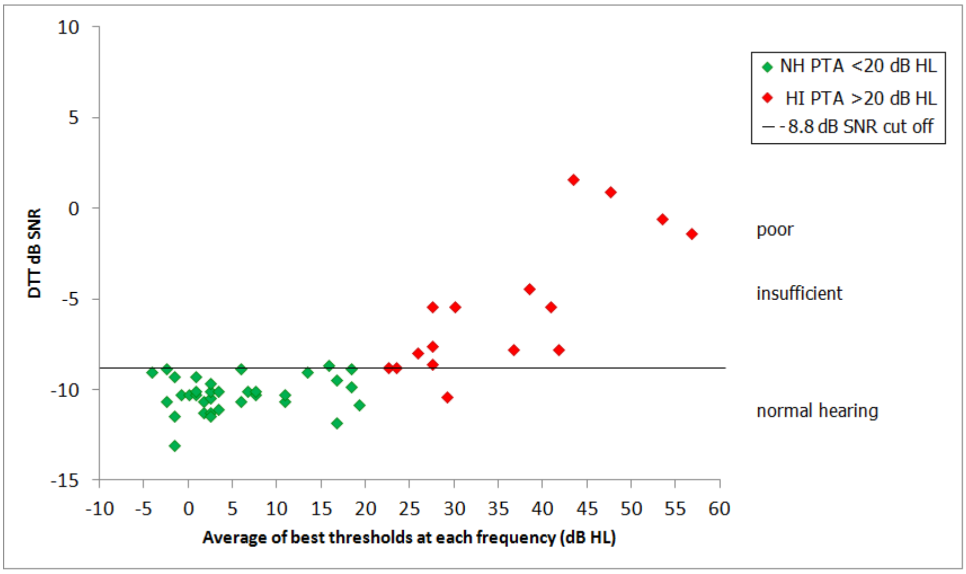

Figure 2.5: A scatterplot of cut-off values for the 'normal' (-8.8 dB SNR) hearing classification for the binaural NZ English DTT when compared to the binaural average of the air-conduction thresholds of the better ear at each frequency (0.25-8 kHz). The 'insufficient' and 'poor' categories assigned by the software were analysed as one category in this research. NB: some participants achieved the same DTT threshold and audiometric threshold, therefore some data points could represent multiple individuals.

For the pilot study, King (2011) had the normal hearing cut off value at -10.3 dB SNR. Which was chosen because it was one SD from the NH mean DTT threshold (M = -12.2 dB SNR, SD = 1.9 dB). However with the change of transducer for the binaural condition, the cut-off value assigned by King (2011) is too conservative for the verification study where stimuli are played into the sound field. For example the NH mean DTT threshold for the verification data is -10.2 dB SNR (SD = 1.0 dB), which is attributed to the stimuli being more difficult to identify in the sound field. If the pilot study cut-off value for normal hearing was applied to the verification data then there would be a much greater number of False Positive test results (21/50) and much fewer True Negative results (13/50), which would have given a very low specificity of 38.2%.

Table 2.5: The cut-off value below which participants are assigned normal hearing status in the current research.

	Verification cut-off
Cut-off	**-8.8**
True Positive	15
False Positive	4
True Negative	30
False Negative	1
Total participants	50
Sensitivity (%)	93.8
Specificity (%)	88.2

Figure 2.6 illustrates the number of presentations for each list for the binaural setting. As the online software randomly chose the lists presented, the researcher did not have the ability to strategically ensure that there were an equal number of presentations for each list. In retrospect, having the lists selectable for this stage of the study would have been optimal.

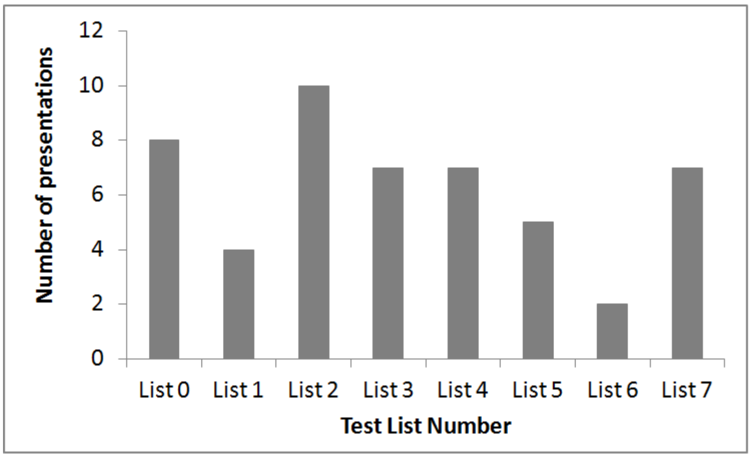

Figure 2.6: The number of binaural presentations of each test list (50 binaural presentations, 8 possible test lists).

2.2.3. Analysis of Separate Ear DTT Results

A total of 100 separate ear results were obtained for the left (n = 50) and right (n = 50) ear. The separate ear characteristics are displayed in Table 2.6. A higher proportion of female ears were in the normal hearing group than male ones; while more than half of the male ears were in the hearing impaired group. The mean age of the hearing impaired ears was 61.1 years for the females and 66.7 years for the males, while the normal hearing ears were much younger; 38.0 years for the females and 35.9 years for the males.

Table 2.6: Data characteristics obtained in the monaural condition for normal hearing (NH) and hearing impaired (HI) ears.

	Number of ears	Right ear (n =)	Left ear (n =)	Mean age (years)	PTA (dB HL)	DTT (dB SNR)
NH Female	44	23	21	38.0 (18.9 SD)	7.1 (5.4 SD)	-11.1 (1.2 SD)
Male	17	8	9	35.9 (16.0 SD)	4.8 (6.9 SD)	-11.6 (1.0 SD)
HI Female	12	5	7	61.1 (23.9 SD)	37.1 (13.0 SD)	-7.9 (3.0 SD)
Male	27	14	13	66.7 (8.7 SD)	38.4 (16.1 SD)	-5.9 (2.9 SD)
Total	100	50	50	48.2 (21.5 SD)	18.7 (18.6 SD)	-9.4 (3.1 SD)

A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between the separate ear PTA (0.25 - 8 kHz) and the separate ear triplet test SNR threshold (n= 100). There was a correlation of r = 0.73 between the two variables in this verification study as shown in Figure 2.7.

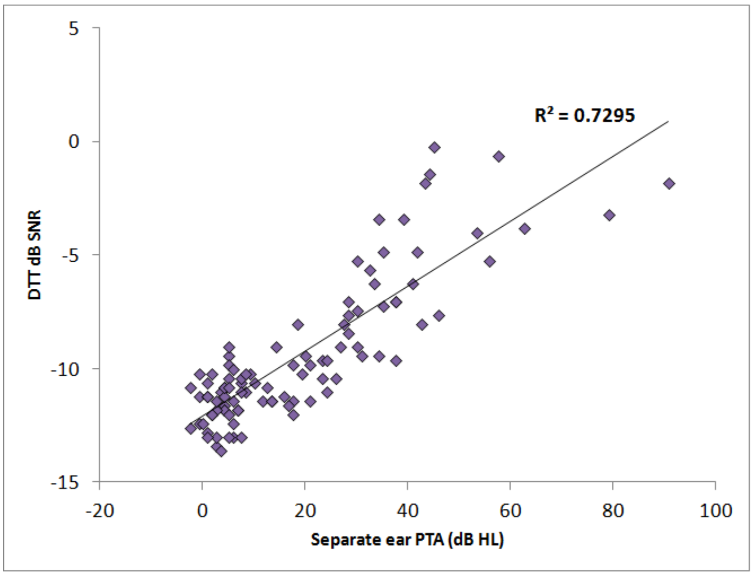

Figure 2.7: Scatterplot of the monaural DTT (dB SNR) correlated with the separate ear average thresholds (0.25-8 kHz); with regression line and R value.

This correlation is not directly comparable to that of the pilot study by King (2011). The pilot study correlation, using the same variables, gave a significant r value of 0.81 ($p < 0.001$). In the pilot study and this verification, participants listened to the monaural stimuli under headphones, unlike the binaural presentation where there was a difference in the transducer used for the pilot study and verification. The fundamental difference between the correlation strength for the two test samples (pilot study 0.81, verification 0.73) is likely to be due to variation in sample size (pilot study 142 ears, verification 100 ears).

In order to determine the reliability of the monaural DTT for identifying hearing loss, a receiver operating characteristic (ROC) curve was created. This curve assesses the true positive rate (sensitivity) and false positive rate (1-specificity) of the test. The DTT threshold was used as the index score, while the PTA score was the reference standard. The red point highlighted on the ROC curve in Figure 2.8 reveals the most sensitive relationship between DTT threshold and PTA reference score. At this point the test sensitivity is 90 % and the specificity is 88 % (1-Specificity is 12 %); the cut-off value for 'normal' hearing is -10.0 dB SNR.

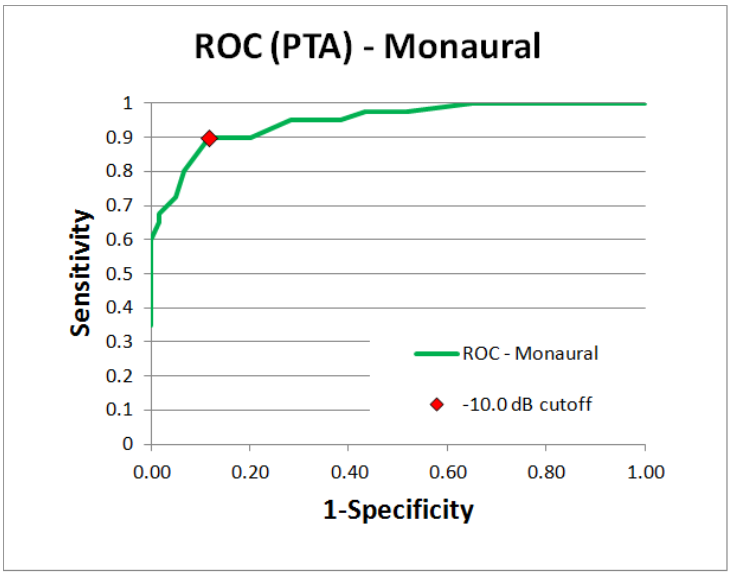

Figure 2.8: Receiver-operating characteristic curve for monaural presentation of the NZ English DTT.

The normal hearing cut off set at -10.0 dB SNR resulted in 43 ears (16 female, 27 male) receiving an insufficient or poor classification (Figure 2.9). This group consisted of 36 correctly identified ears with air-conduction PTA thresholds (0.25-8 kHz) of >20 dB HL (True Positive), and seven incorrectly identified ears that actually had PTA thresholds <20 dB HL (False Positive). On closer examination of those seven ears; two had mild high frequencies losses and one had a moderate loss in the high frequencies, another two of the ears had normal air conduction thresholds but type Ad tympanograms; both of these ears were from the same individual. One of the seven ears had a mild hearing loss at 250 Hz, with borderline 20 dB HL thresholds for 2-8 kHz; this individual was also 80 years old. This illustrates that averaging of thresholds (0.25-8 kHz) can potentially conceal high frequency hearing loss or asymmetry (Aazh & Moore, 2007).

The final ear given false positive status belonged to a 20 year old female with normal air conduction thresholds at all frequencies and tympanometry, suggesting that attention or processing issues contributed to the low score of that ear. However, it was not possible to ascertain the cause of her poor performance as further testing would be needed that was outside the scope of this study.

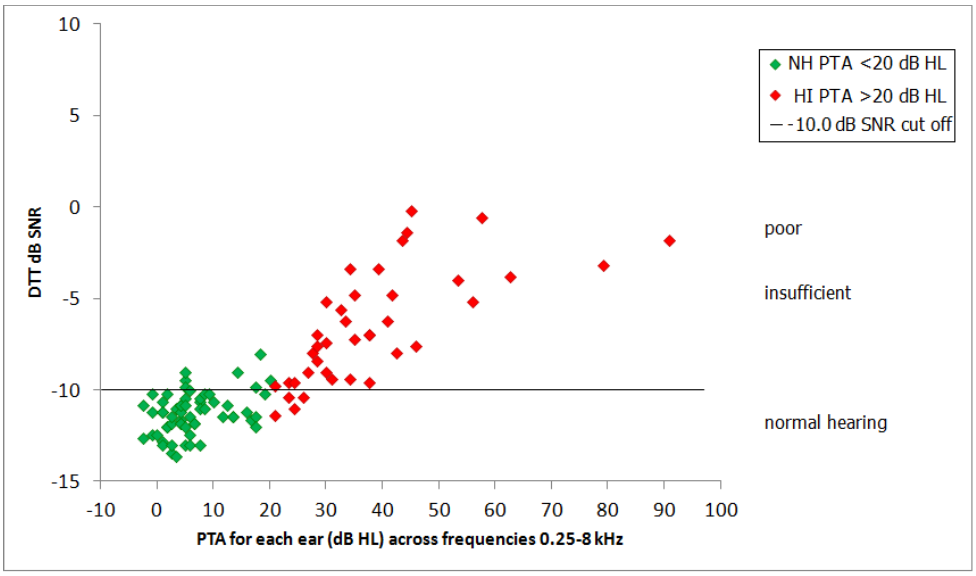

Figure 2.9: A scatterplot of cut-off values for 'normal' (-10.0 dB SNR) hearing classification for the monaural NZ English DTT when compared to the monaural average of the air-conduction thresholds of each ear at frequencies 0.25-8 kHz. The 'insufficient' and 'poor' categories assigned by the software were analysed as one category in this research. NB: some participants achieved the same DTT threshold and audiometric threshold, therefore some data points could represent multiple individuals.

For the pilot study, King (2011) had the normal hearing cut off value at -10.4 dB SNR. Which was chosen because it was one SD from the monaural NH mean DTT threshold (M = -12.15 dB SNR, SD = 1.75 dB). However the cut-off value assigned by King (2011) is too conservative for the verification study. The monaural NH mean DTT threshold for the verification data is -11.2 dB SNR (SD = 1.2 dB). If the pilot study cut-off value for normal hearing (-10.4 dB SNR) was applied to the verification data then there would be twice the number of False Positive results (14/100) and fewer True Negative results (46/100). The -10.0 dB cut-off improves the specificity of the DTT, thereby providing greater test reliability (Table 2.7).

Table 2.7: Two cut-off values, below which participants are assigned normal hearing status in the current research.

	Verification cut-off
Cut-off	**-10.0**
True Positive	36
False Positive	7
True Negative	53
False Negative	4
Total participants	100
Sensitivity (%)	90.0
Specificity (%)	88.3

2.2.4. Responses of Hearing Self-Evaluation

At the beginning of the assessment, participants were asked to assign a number between 1 (very poor) and 5 (excellent) to rank their overall hearing ability in everyday life. A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between (a) the binaural DTT score (dB SNR) and the individual's perception of their own hearing ability (n= 50), and (b) the binaural PTA dB HL (averaged over the better thresholds of the two ears) and the individual's perception of their own hearing ability (n = 50). Figure 2.10(a) shows that individuals who score better on the DTT (have more negative SNRs) perceive their own hearing very favourably, while those who score poorly on the DTT are more likely to have a poor perception of their hearing ability. The r value for this correlation is 0.55, suggesting that a relationship exists between the two variables. Figure 2.10(b) illustrates the correlation (r value = 0.48) between binaural PTA db HL and personal valuation of hearing ability. Individuals with an elevated PTA tend to score their hearing ability more poorly than those who have a PTA within the normal hearing range.

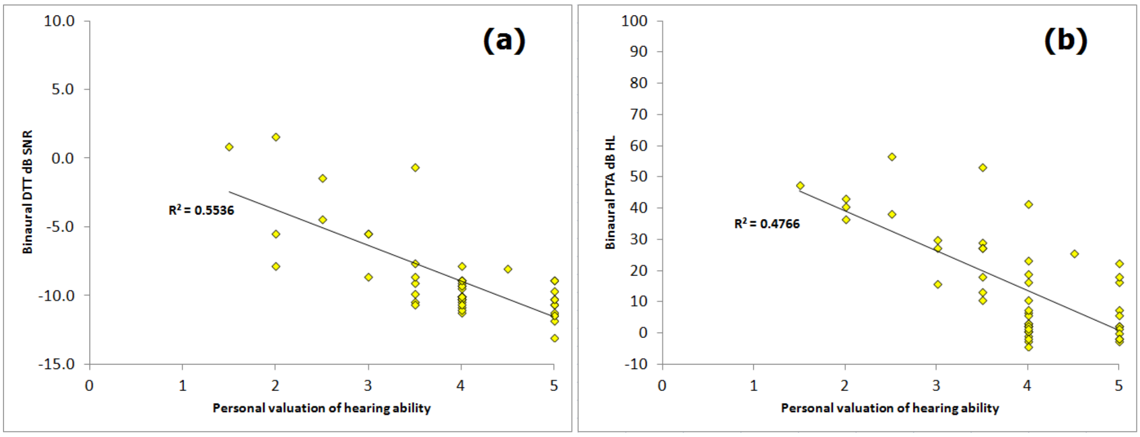

Figure 2.10: Scatterplot and linear regression of (a) the binaural DTT (dB SNR) correlated with the personal valuation of hearing ability, and (b) the binaural average of the thresholds of the better ear at each frequency (0.25-8 kHz) correlated with the personal valuation of hearing ability; with regression lines and R values.

Figure 2.11 shows the relationship between participant age and binaural PTA. In general, increasing age of participants results in elevation in binaural air-conduction thresholds (0.25-8 kHz). A Pearson's product-moment correlation co-efficient was produced and an r value of 0.53 was generated to quantify this relationship. There are more male participants aged 60 years or older, and therefore there are a greater number of males (than females) with binaural PTA thresholds ≥20 dB. A greater number of participants of all ages would be required to generalise whether older New Zealand English speaking males have a greater incidence of hearing loss than younger males and females or their older female counterparts.

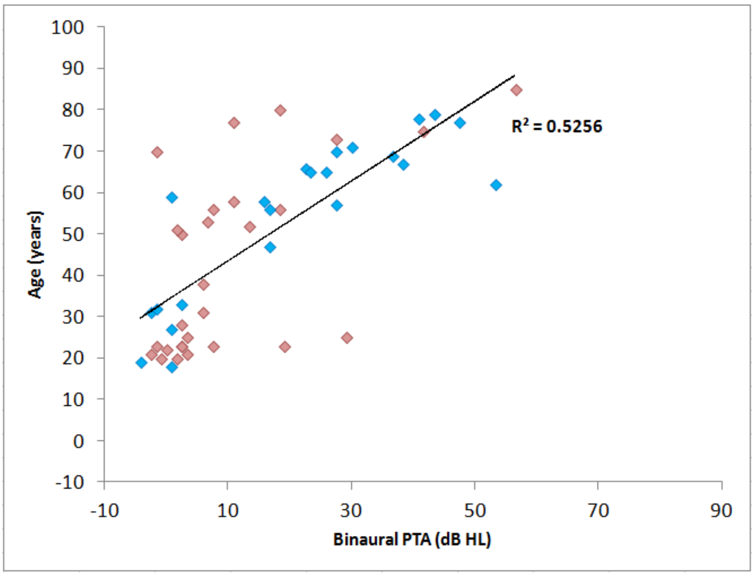

Figure 2.11: Scatterplot and linear regression of the relationship between the age of the participants and their binaural PTA (average of the thresholds of the better ear at frequencies 0.25-8 kHz); with regression lines and R values. Female participants = rose, male participants = blue.

Chapter 3 PART B: PILOT STUDY

3.1 METHODOLOGY FOR THE PILOT STUDY

This section describes the methods used in the pilot study of the Te Reo Maori digit-triplets for the internet version of the New Zealand Hearing Screening Test. The subheadings below detail the participant characteristics, the types of instrumentation used and the procedures undertaken during the pilot study.

3.1.1. PARTICIPANTS

Twenty-nine individuals participated in this pilot study of the Te Reo Maori version of the NZHST. They were staff or students of the University of Canterbury or members of the surrounding Christchurch community. The data from two participants were excluded as they could not complete all three testing conditions, leaving 27 participants from whom DTT results were gathered and analysed. The age and sex distribution of the remaining 27 participants is displayed in Table 3.1. Twenty-one females and 6 males participated; with the largest proportion of both genders in the 18 to 30 years category.

Table 3.1: The age/sex distribution of the participants for the Te Reo Māori pilot study.

	Age				
Sex	**18y-30y**	**31y-45y**	**46y-60y**	**61y+**	**Total**
Female	8	7	2	4	21
Male	4	1	1	0	6
Total	12	8	3	4	27

3.1.2. INSTRUMENTATION

This pilot study was also undertaken at the Department of Communication Disorders, where the audiological equipment is shared between researchers, students and the University of Canterbury Speech and Hearing Clinic. Therefore three different equipment configurations were used throughout the Te Reo version pilot study and they are described in Table 3.2. A biological calibration of each of these audiometer configurations is performed twice weekly.

Table 3.2: The three audiometer and earphone configurations used to obtain the octave-frequency pure-tone thresholds for each participant in this research.

	Audiometer specifications	Insert earphones	Supra-aural earphones	No. of participants tested using each configuration
Configuration 1	Interacoustics Diagnostic Audiometer AD229e (SN 553462)	Eartone 5A insert earphones Right (SN5A10_05946) Left (SN 5A10_05945)	Telephonics TDH-39P earphones Right (SN C348614) Left (SN C348613)	10 with insert earphones 0 with supra-aural earphones
Configuration 2	Grason-Stadler GSI 61clinical two-channel audiometer (SN AA051664)	Eartone-3A insert earphones Right (SN 20678) Left (SN 20677)	Telephonics TDH-50P earphones Right (SN C64094) Left (SN C64093)	9 with insert earphones 4 with supra-aural earphones
Configuration 3	Grason-Stadler GSI 61clinical two-channel audiometer (SN AA083951)	Eartone-3A insert earphones Right (SN C70590) Left (SN C70589)	Telephonics THD-50P earphones Right (SN C70588) Left (SN C70587)	4 with insert earphones 0 with supra-aural earphones

Furthermore, this shared access to instrumentation meant that three devices were used in this study to assess tympanometric measures of ear health and rule out conductive components to hearing loss. These instruments are described in Table 3.3.

Table 3.3: The two instruments used to obtain tympanometric measures in this research.

	Tympanometer specifications	No. of participants tested using each tympanometer
Tympanometer 1	Grason-Stadler GSI TympStar Middle Ear Analyzer (SN AL062374)	15
Tympanometer 2	Interacoustics MT10 (SN 151784)	11
Tympanometer 3	GN Otometrics Madsen Otoflex 100 (SN 218847)	1

The speech material used for the Te Reo version of the New Zealand Hearing Screening Test was recorded Te Reo digits embedded in speech noise (Murray, 2012). The recorded digits were spoken by a female who was fluent in Te Reo Māori. She had read several lists of digit triplets, with a carrier phrase i.e. “ko nga nama: tahi-iwa-rima” (translated as “the numbers: one-nine-five”) using natural intonation. Each of the nine disyllabic digits of Te Reo (0 to 9, excluding monosyllabic 4) had been said in all three positions in the triplet. These were then split into separate sound files for normalization and use in the test. Detailed analysis of the recording and normalization of these digit triplet lists can be found in the thesis of Murray (2012).

The speech noise used in this research was generated by randomly superimposing individual Te Reo digit recordings on top of each other 10, 000 times within a 10 second looped sound file, creating a speech noise file with a spectrum that was almost identical to that of the digits (signal). This similar spectral content means that the signal-to-noise (SNR) of the stimuli would not be altered by filtering at the transducer level (within certain limits), as the signal and noise would be equally filtered if it they passed through a band-limited filter such as a land-line telephone or broadband signal. Further analysis and a power spectra of the signal and noise were provided by Murray (2012).

The laptop computer from which the DTT and speech noise were played was an HP Compaq nx6120 (SN CNU510GTCL) using the Windows XP operating system. The transducers used to present the stimuli to the participants' ears were Sennheiser HD215 earphones that were coupled to the laptop via a Buddy 6G USB soundcard (InSyncSpeechTechnologies, 2012).

3.1.3. Interview and Audiometry Procedure

The informal interview and audiometric procedure were undertaken in the sound treated rooms (mean sound level = 29.5 dB A) of the Speech and Hearing Clinic at the Department of Communication Disorders (University of Canterbury, New Zealand) between May and October 2012. Each participant was tested individually at scheduled appointments arranged via email. The appointment began with an unstructured interview where the procedure was explained to the participant and they were asked to sign a consent form with the understanding that their test results would be de-identified and would be destroyed after 5 years. They were also given the opportunity to enter the same prize draw as the verification study. The participant was then asked their date of birth and was asked to rate both their familiarity with Te Reo digits and their hearing ability on a scale of 1 to 5 (where 1 was very poor and 5 was excellent).

Otoscopy was performed to assess the health of the external auditory canal and tympanic membrane, and to ensure that if cerumen was present it would not interfere with audiometric testing. The participant then received a diagnostic hearing test using one of the audiometer and earphone configurations displayed in Table 3.2. Pure-tone audiometry was used as the diagnostic hearing test in the same manner as the verification research (Section 2.1.4).

Objective measures of tympanic membrane health were then determined via tympanometry, using one of the tympanometers described in Table 3.3. This was to identify the presence of any conductive component such as middle ear fluid or tympanic membrane retraction. The DTT is a test for sensorineural hearing loss, so it was important to be aware of any conductive components. A purely conductive hearing loss would not negatively affect DTT performance, but would cause elevated PTA thresholds. The type of tympanogram, the middle ear pressure, static compliance, equivalent ear canal volume and tympanic width were recorded for each ear of every participant.

Each participant had their pure-tone audiometry and tympanometry results explained to them. In cases where a hearing loss was found, a full diagnostic hearing test was suggested and support services such as the Hearing Association were recommended.

3.1.4. Digit Triplet Test Procedure

Participants were seated at a laptop with earphones to play the sound stimuli. They were told they would hear a recording of a woman saying lists of three-digit phrases preceded by the carrier phrase "ko nga nama", in the presence of a background noise. They were instructed to enter the digit-triplets into the computer number keypad in the order that they were presented. There were 8 possible lists of 27 digit-triplets that could be used; 3 lists were strategically selected and presented to the left, right, and binaurally for each person (Table 3.4).

Table 3.4: Presentation order of Te Reo Maori DTT lists for the first five participants

Participant	First Trial	List	Second Trial	List	Third Trial	List
1	Right	1	Left	2	Binaural	3
2	Left	4	Right	5	Binaural	6
3	Binaural	7	Left	8	Right	1
4	Right	2	Binaural	3	Left	4
5	Left	5	Binaural	6	Right	7

The participants were told that the DTT was trying to find the level at which speech was only just perceptible, and were reassured to not be concerned if the digits became increasingly inaudible; they were instructed to just enter what they thought they heard, or if they had no idea then enter any digit into the number pad and press enter.

To be a correct triplet, all of the digits entered into the keyboard had to be identical in number and sequence to those presented to through the earphones. Participants were not informed that the digit 4 (wha) was omitted, but were told that 0-9 were possible response options.

After completing the 3 lists, the participants were thanked for their time and were provided with any information regarding coping strategies or further diagnostic assessment if a hearing loss was discovered. The comprehensive results of each participant were automatically placed in a .txt file on the desktop, which was created at the completion of each list.

3.2 PILOT STUDY RESULTS

This section analyses the participant characteristics and divides them into two groups based on air conduction PTA (0.25 - 8 kHz). The correlation between the participants' DTT scores and PTA thresholds is also quantified. The sensitivity and specificity of the Te Reo Maori DTT as a screening test for hearing loss is also described through the use of receiver operating characteristic (ROC) curves; and cut-off DTT values are chosen for the different hearing classifications.

3.2.1. AUDIOMETRIC RESULTS OF THE PILOT STUDY

The participant results were divided into two groups on the basis of hearing ability; individuals assigned to Group 1 had normal hearing and individuals assigned to Group 2 had hearing loss (Figure 3.1). Normal hearing was defined as having air-conduction pure tone thresholds of ≤ 20 dB HL for each of the six audiometric octave frequencies (0.25 - 8 kHz) in each ear, or if one or more thresholds exceeded 20 dB HL in one ear but the total PTA (0.25 - 8 kHz) of the better ear was ≤ 20 dB HL.

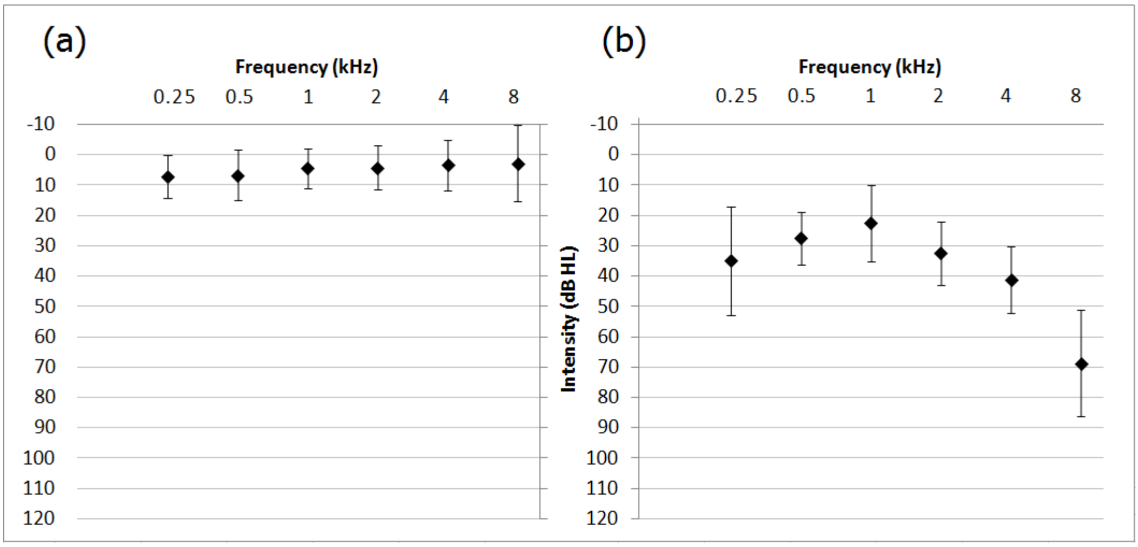

Figure 3.1: Average air-conduction pure tone thresholds for (a) Group 1 (n = 23) and (b) Group 2 (n = 4)

Analysis of the characteristics of each group follows: individuals in Group 1 had normal or essentially normal hearing; 17 females (Mean age = 32.6, SD ± 13.0 years, PTA M = 4.4 dB HL, SD ± 6.7 dB HL, DTT threshold M = -8.5 dB SNR, SD ± 1.1 dB), 6 males (Mean age= 31.5, SD± 11.7 years, PTA M = 6.1 dB HL, SD ± 11.8 dB HL, DTT threshold M = -9.8 dB SNR, SD ± 0.7 dB). Those in Group 2 had some degree of hearing impairment and all 4 individuals in this group were female (Mean age = 67.3, SD ± 12.8 years, PTA M = 37.9 dB HL, SD ± 13.0 dB HL, DTT threshold M = -0.6 dB SNR, SD ± 5.6 dB).

3.2.2. Analysis of Binaural DTT results

A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between the binaural average of thresholds in the better ear at each frequency (0.25 - 8 kHz) and the binaural triplet test SNR threshold (n= 27). There was a correlation of r = 0.61 between the two variables as shown in Figure 3.2. This means that 61.3 % of the data could be represented by the trendline. The strength of this correlation could be improved with a greater number of participants with PTA (0.25-8 kHz) thresholds >20 dB HL. In this dataset there are only 4 individuals with hearing impairment, therefore the correlation between the two variables in Figure 3.2 must be interpreted with caution.

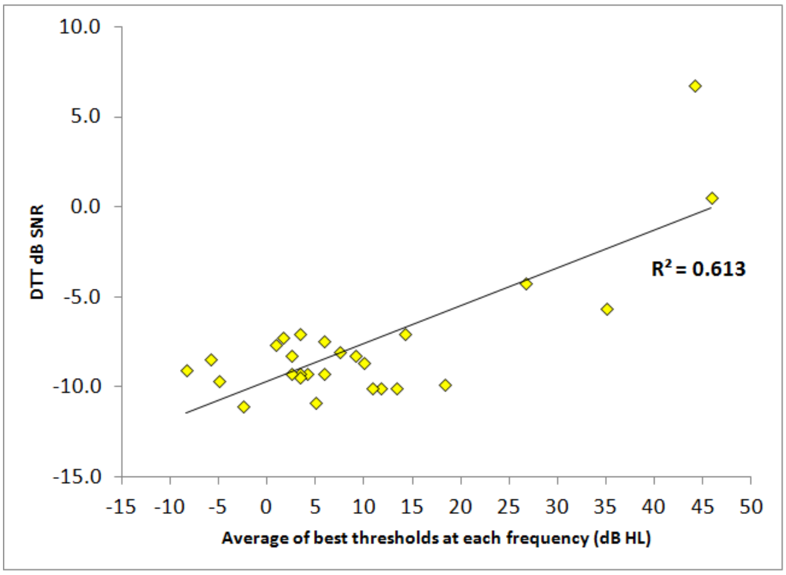

Figure 3.2: Scatterplot of the binaural DTT (dB SNR) correlated with the binaural average of the thresholds of the better ear at each frequency (0.25-8 kHz).

In order to determine how reliable the binaural DTT is at identifying hearing loss a receiver operating characteristic (ROC) curve was created. This curve assesses the true positive rate (sensitivity) and false positive rate (1-specificity) for the binaural triplet test. The DTT threshold was used as the index score, while the PTA score was the reference standard. The red point highlighted on the ROC curve in Figure 3.3 reveals the most sensitive relationship between the DTT threshold and PTA reference score. At this point both the test sensitivity and specificity are 100 % (1-Specificity is 0 %); the cut-off value for 'normal' hearing is -6.8 dB SNR.

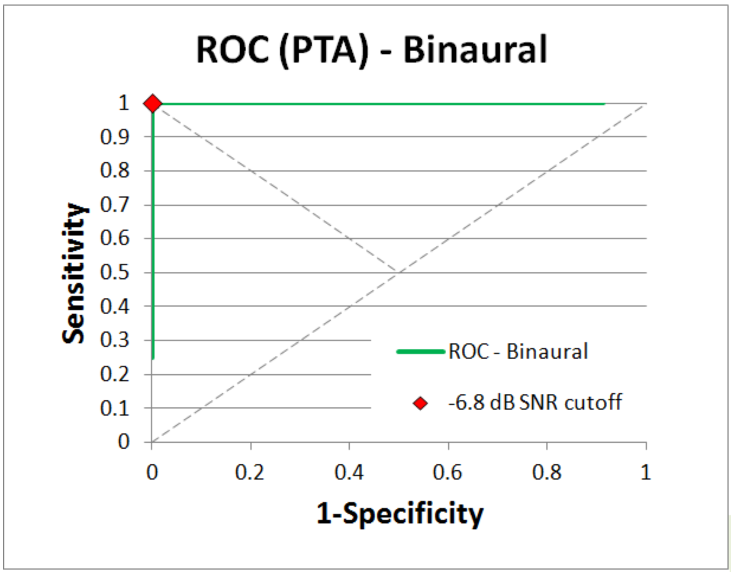

Figure 3.3: Receiver-operating characteristic curve for binaural presentation of the Te Reo Maori DTT.

The normal hearing cut-off set at -6.8 dB SNR resulted in all four participants of Group 2 being correctly identified as having hearing impairment (True Positive) and all individuals in Group 1 being correctly identified as having normal hearing (True Negative) (Figure 3.4). However the ability of the test to differentiate normal hearing from hearing impairment is called in to question by the lack of participants, especially those with a mild to moderate loss.

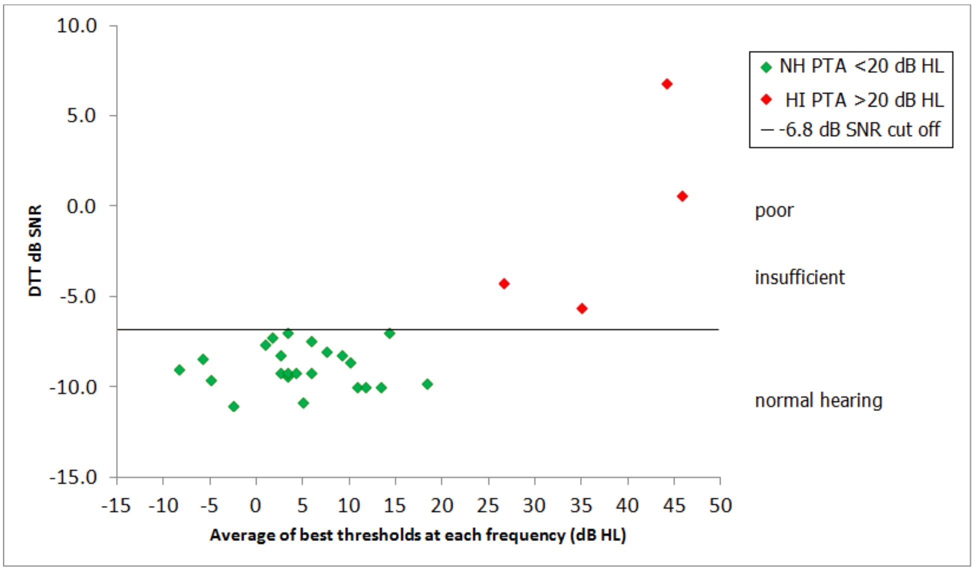

Figure 3.4: A scatterplot of cut-off values for 'normal' (-6.8 dB SNR) and 'poor' (X.X dB SNR) hearing classifications for the binaural Te Reo Māori DTT when compared to the binaural average of the air-conduction thresholds of the better ear at each frequency (0.25-8 kHz).

Figure 3.5 illustrates the number of times each of the eight lists was presented during this part of the research. List 6 was presented the greatest number of times, and list 1 the least.

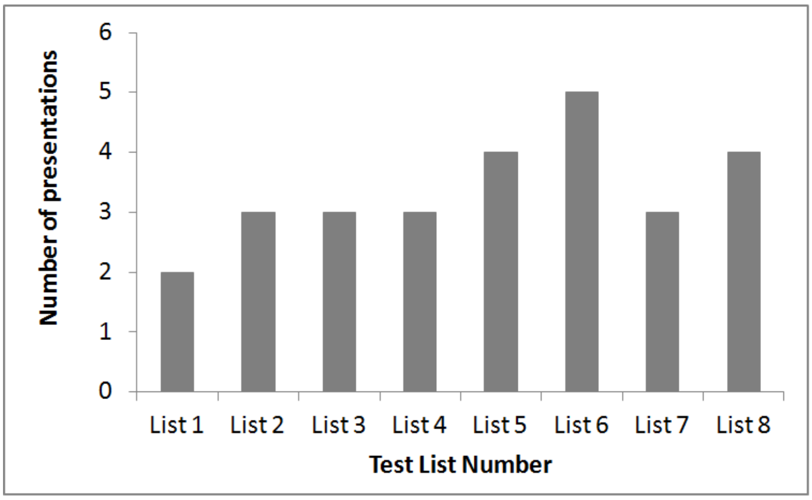

Figure 3.5: The number of binaural presentations of each test list (27 binaural presentations, 8 possible test lists).

3.2.3. Analysis of Separate Ear DTT Results

A total of 54 separate ear results were obtained for the left (n = 27) and right (n = 27) ear. The separate ear characteristics are displayed in Table 3.5. There were more female ears than male ears in both the normal hearing and hearing impaired groups, with only one male in the HI group. The mean age of the hearing impaired ears was 62.1 years for the females, while the normal hearing ears were much younger; 32.9 years for the females and 32.2 years for the males. Ears with normal hearing could generally identify the digit-triplets with a poorer SNR than the hearing impaired ears – excluding the performance of the solitary HI 28 year old male (Table 3.5).

Table 3.5 Data characteristics obtained in the monaural condition for normal hearing (NH= average threshold of each ear ≤20 dB, averaged over 0.25-8 kHz) and hearing impaired (HI= average threshold of each ear >20 dB, averaged over 0.25-8 kHz) ears. The data for HI males is from one individual (*).

	Number of ears	Right ear (n =)	Left ear (n =)	Mean age (years)	PTA (dB HL)	DTT (dB SNR)
NH Female	33	17	16	32.9 (12.8 SD)	6.1 (5.2 SD)	-7.2 (1.8 SD)
Male	10	5	5	32.2 (12.8 SD)	5.1 (9.3 SD)	-8.3 (1.3 SD)
HI Female	9	4	5	62.1 (19.0 SD)	42.4 (16.0 SD)	2.2 (7.3 SD)
Male	2	1	1	28.0* (0.0 SD)	21.3* (1.8 SD)	-9.1* (1.0 SD)
Total	54	27	27	37.5 (17.4 SD)	12.5 (16.2 SD)	-5.6 (6.6 SD)

A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between the separate ear PTA (0.25 - 8 kHz) and the separate ear triplet test SNR threshold (n= 54). There was a correlation of r = 0.63 between the two variables as shown in Figure 3.6. The strength of this correlation could be improved with a greater number of hearing impaired ears (PTA for 0.25-8 kHz with thresholds >20 dB HL). In this dataset there are only 11 ears with hearing impairment, therefore the correlation between the two variables in Figure 3.6 must be interpreted with caution.

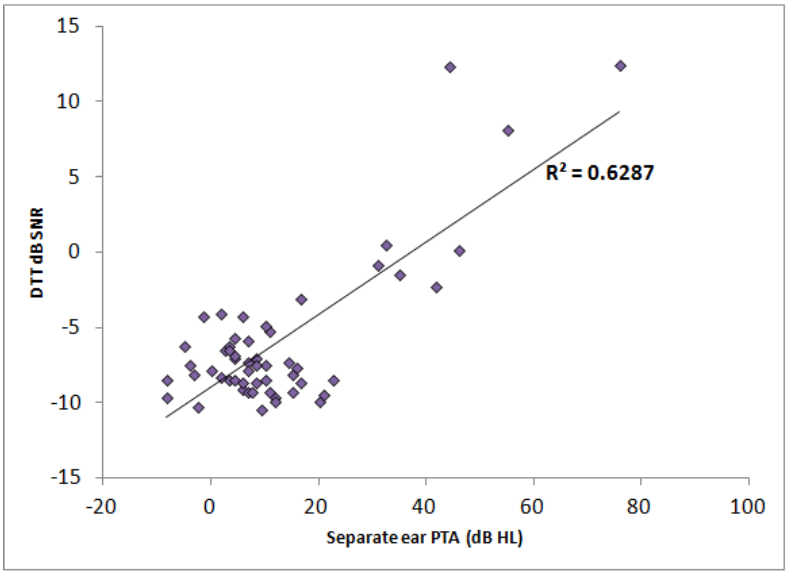

Figure 3.6: Scatterplot of the monaural DTT (dB SNR) correlated with the separate ear average thresholds (0.25-8 kHz); with regression line and R value.

In order to determine how reliable the monaural DTT is at identifying hearing loss a receiver operating characteristic (ROC) curve was created. This curve assesses the true positive rate (sensitivity) and false positive rate (1-specificity) for the monaural triplet test. The DTT threshold was used as the index score, while the PTA score was the reference standard. The red point highlighted on the ROC curve in Figure 3.7 reveals the most sensitive relationship between the DTT threshold and PTA reference score. At this point the test sensitivity is 72.7% and the specificity is 100 % (1-Specificity is 0 %); the cut-off value for 'normal' hearing is -2.8 dB SNR.

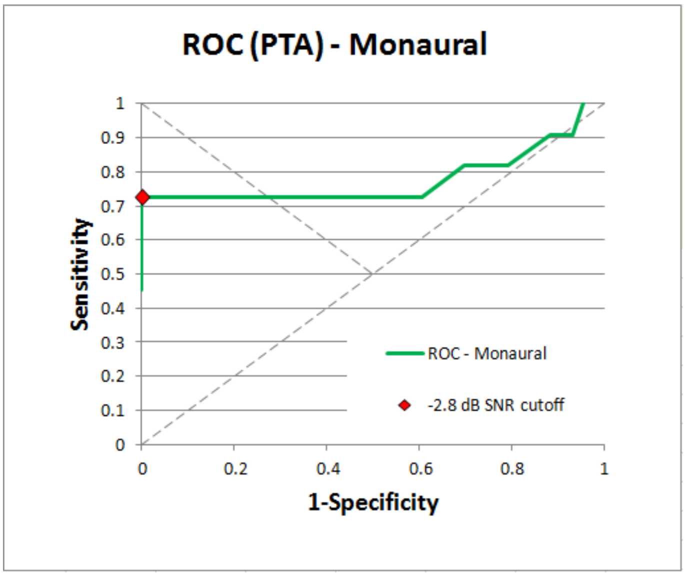

Figure 3.7: Receiver-operating characteristic curve for monaural presentation of the Te Reo Māori DTT.

The normal hearing cut-off of -2.8 dB SNR resulted in eight of the 11 ears with hearing impairment being correctly identified (True Positive) (Figure 3.8). The three remaining ears were incorrectly identified as having normal hearing by the DTT (False Negative). On closer analysis of these three ears; one was the right ear of a 21 year old female with a mild unilateral low frequency loss from 0.25-1 kHz, while the other two ears belonged to a 28 year old male with a mild loss at 0.25 kHz on the right and a moderate (right) to moderately severe loss (left) at 8 kHz.

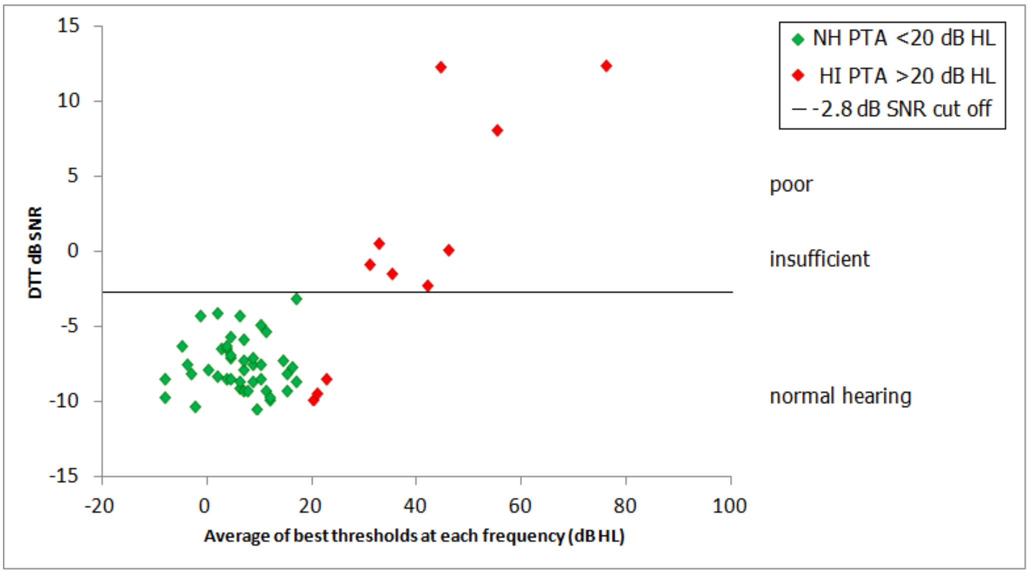

Figure 3.8: A scatterplot of cut-off values for 'normal' (-6.8 dB SNR) and 'poor' (X.X dB SNR) hearing classifications for the monaural Te Reo Māori DTT when compared to the monaural average of the air-conduction thresholds (0.25-8 kHz).

Although these three ears have elevated thresholds at particular frequencies, the cognitive abilities of these young adults may have resulted in adequate processing of the degraded speech signal, so that their DTT score was analogous to those with normal hearing (Getzmann & Falkenstein, 2011). All ears with normal hearing (PTA 0.25-8 kHz <20 dB) were correctly identified by the DTT as having normal hearing (True Negative), meaning test specificity was 100%. However the lack of participants with a mild to moderate loss means the reliability of this Te Reo Māori DTT is not certain.

3.2.4. Responses of Hearing Self-Evaluation

At the beginning of the assessment, participants were asked to assign a number between 1 (very poor) and 5 (excellent) to rank their overall hearing ability in everyday life. A Pearson's product-moment correlation co-efficient was generated to quantify the relationship between (a) the binaural DTT score (dB SNR) and the individual's perception of their own hearing ability (n= 27), and (b) the binaural PTA dB HL (averaged over the better thresholds of the two ears) and the individual's perception of their own hearing ability (n = 27) (Figure 3.9). There is a weak correlation (r value = 0.23) between poorer binaural DTT scores and decreasing perception of hearing ability. The correlation between poorer binaural PTA thresholds and decreased perception of hearing ability is stronger with an r value of 0.45.

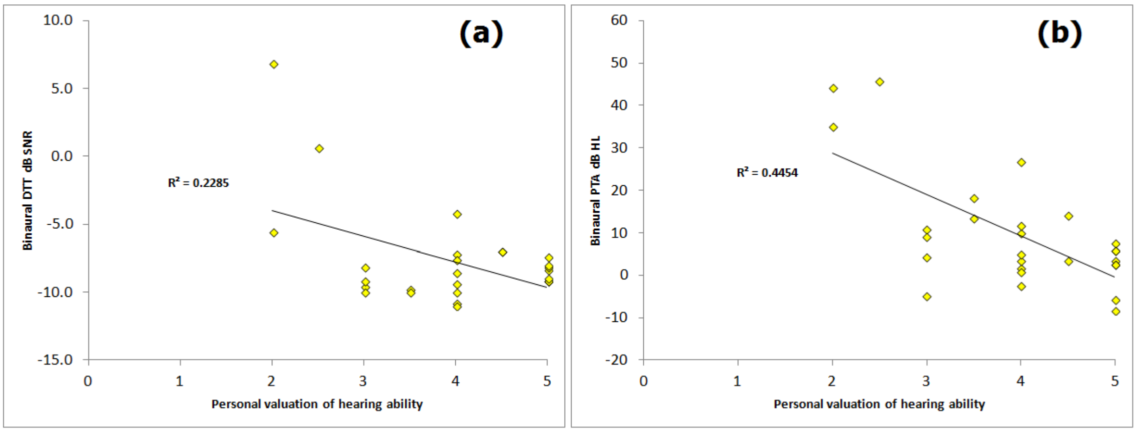

Figure 3.9: Scatterplot and linear regression of (a) the binaural DTT (dB SNR) correlated with the personal valuation of hearing ability, and (b) the binaural average of the thresholds of the better ear at each frequency (0.25-8 kHz) correlated with the personal valuation of hearing ability; with regression lines and R values.

The relationship between participant age and binaural PTA for the Te Reo Maori DTT participants is shown in Figure 3.10. In general, an increase in participant age results in an elevation in binaural air-conduction thresholds (0.25-8 kHz). A Pearson's product-moment correlation co-efficient produced an r value of 0.52. All of the male participants were aged 50 years or younger, and thus there were a greater number of females (than males) with binaural PTA thresholds ≥20 dB. In order to generalise the results of this research to the Te Reo Maori speaking population, a larger number of participants (of all ages) are be required. Due to the lack of participants with hearing impairment (PTA > 20 dB HL), the ability of the DTT to identify hearing loss cannot be assured.

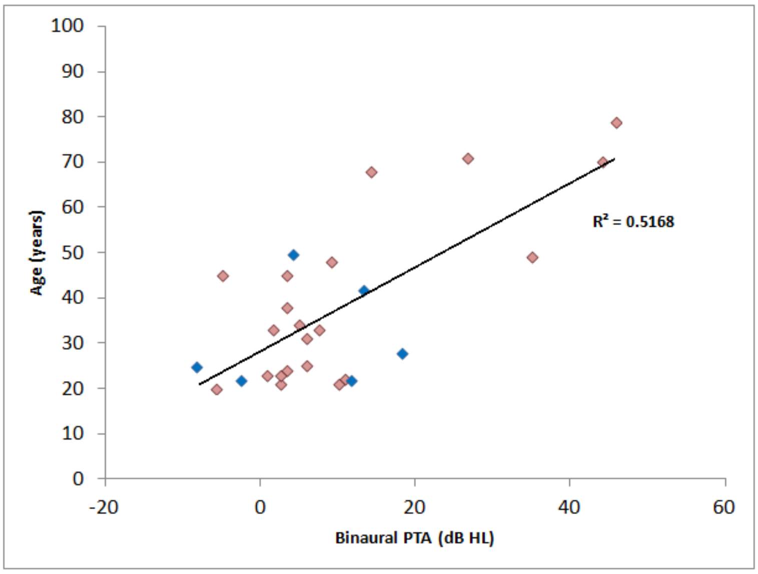

Figure 3.10: Scatterplot and linear regression of the relationship between the age of the participants and their binaural PTA (average of the thresholds of the better ear at frequencies 0.25-8 kHz); with regression line and R value. Female participants = rose, male participants = blue.

The data displayed in Figure 3.11 shows that many of the participants were not confident in their familiarity with the digits of Te Reo Māori. Despite this, many of them were able to achieve low DTT scores. However two individuals who performed particularly poorly on the DTT rated their familiarity with the Te Reo Maori digits as 2 and 2.5 out of 5.

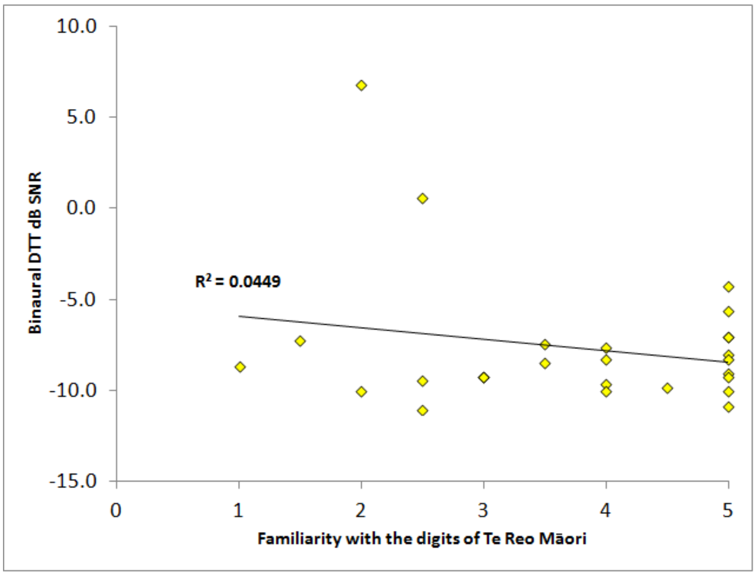

Figure 3.11: Scatterplot and linear regression of the relationship between the participants' familiarity with the digits of Te Reo Māori (1= poor, 5 = excellent) and their binaural DTT; with regression line and R value.

Chapter 4 PART C: NORMALISATION

4.1 METHODOLOGY FOR DIGIT NORMALISATION

This section describes the methods used in the normalisation of the New Zealand English digits for the telephone version of the New Zealand Hearing Screening Test. The subsections below detail the participant characteristics, the types of instrumentation used and the procedures undertaken during the normalisation process.

4.1.1. PARTICIPANTS

Ten individuals participated in the normalisation of the New Zealand English digit-triplets for the telephone version of the NZHST. They were staff or students of the University of Canterbury, clients of the University of Canterbury Speech and Hearing Clinic, or members of the surrounding Christchurch community. The age and sex distribution of the 10 participants are displayed in (Table 4.1). The participants ranged in age from 19 years to 37 years, the majority of them were female (n = 7). All participants had normal hearing across the six audiometric octave frequencies (0.25-8 kHz).

Table 4.1: The age/sex distribution of the participants for the NZ English test verification.

	Age		
Sex	**18y-30y**	**31y-45y**	**Total**
Female	6	1	7
Male	1	2	3
Total	7	3	10

4.1.2. INSTRUMENTATION

The digit normalisation was undertaken in Resound Booth 2, a sound proof booth in the Rutherford Building at the University of Canterbury. Participants had audiometric test results that showed normal hearing within 6 months of the normalisation task, so new audiometric testing was not required.

The speech material used for the telephone normalisation of the New Zealand English DTT, was identical to that of the internet version (King, 2011). It utilised the same recording of a 26 year old female speaking the digit triplets, with a carrier phrase i.e. “The digits: one-two-one”.

There were two types of speech noise used in this research; the first was a standard continuous speech noise that was generated by randomly superimposing the 24 individual digit recordings on top of each other 10, 000 times creating a speech noise file with a spectrum that was almost identical to that of the digits (signal). Further analysis and a power spectrum of the continuous speech noise is provided by King (2011). The second type of noise is a “spectral and temporal gap (STG) noise” that was created as described in Section 4.1.3 below. The similar spectral content of both noise types and the speech stimuli meant that the signal-to-noise (SNR) would not be altered by filtering at the transducer level (within certain limits), as the signal and noise would be equally filtered if it they passed through the band-limited filter of a land-line telephone.

The transducer used for this testing was a standard land-line telephone handset. Audio signals were played through a Buddy 6G USB soundcard (InSyncSpeechTechnologies, 2012) to a THAT-2 telephone interface (JK Audio Inc.) that sat between the handset and telephone of a Pacific 723L telephone. This telephone was used to dial a telephone of the same model in the sound proof booth which the participant used to listen to the DTT (Figure 4.1).

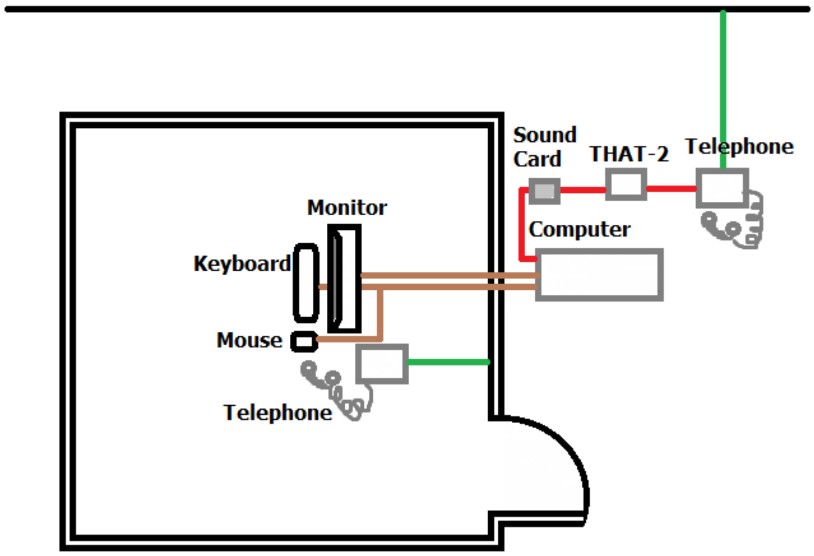

Figure 4.1: A schematic diagram of the instrument setup for normalisation.

4.1.3. Spectral and Temporal Gap (STG) Noise

As described in section 1.3.1, both spectral gaps and temporal gaps have the potential to increase the sensitivity of screening tests that aim to differentiate between normal hearing listeners and those with cochlear hearing losses. Listeners with normal hearing are able to take advantage of masking release whereas listeners with impaired temporal and spectral resolution are not. This study employed a novel type of noise (STG noise; (O'Beirne, 2011)) that incorporated both spectral and temporal gaps.

The first step in generating this noise involved creating two separate speech noise files with opposite temporal gaps. This was done by multiplying the speech noise sample with a 16 Hz trapezoid (10% rise-fall time) or with the opposite function (i.e. one that is 180 degrees out of phase), as shown in Figure 4.2.

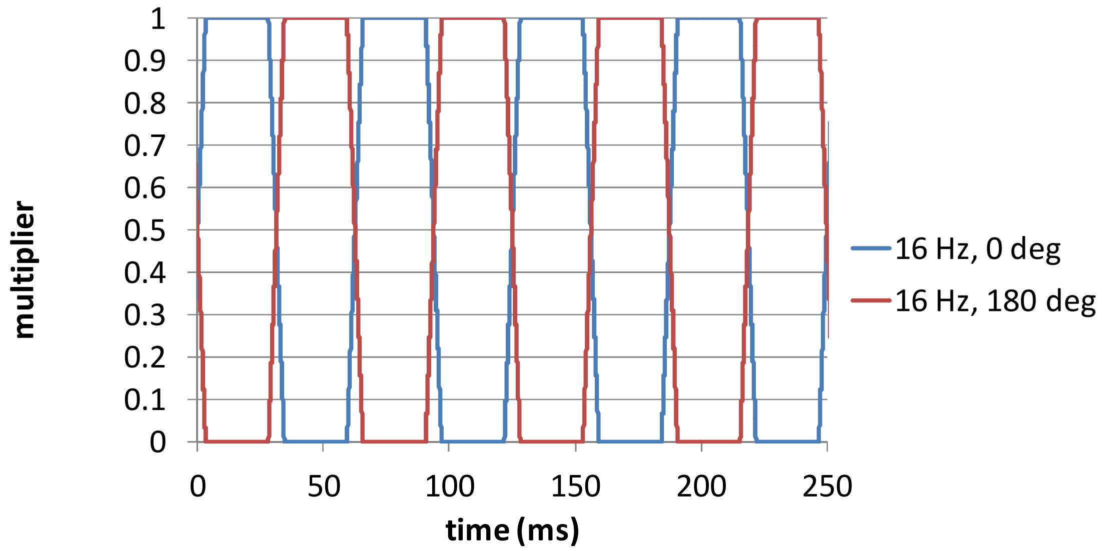

Figure 4.2: Multiplier waveforms that were used to create the temporal gaps.

The two resulting noise files had complementary 16 Hz temporal gaps that were 100% modulated, such that addition of the two waveforms resulted in the original unmodified file.

Spectral gaps that were two equivalent rectangular bandwidths (ERBs) wide were then introduced to the two noise files by multiple band-pass filtering. Figure 4.3 shows the spectrum of the speech noise used in the study with vertical grey lines indicating ERBs according to the formula of Glasberg & Moore (1990).

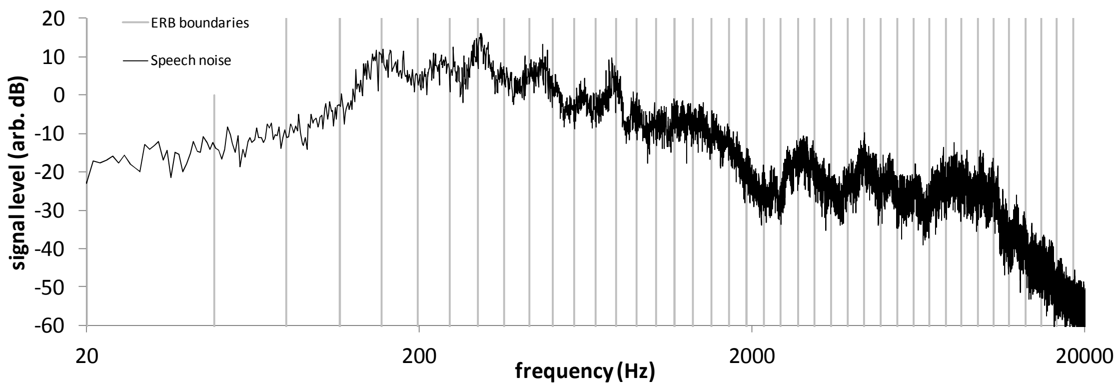

Figure 4.3: The spectrum of the New Zealand English speech noise used in this study, with a visual representation of equivalent rectangular bandwidth boundaries calculated according to the formula of Glasberg and Moore (1990).

The ringing introduced by the filtering resulted in the 100% modulation produced by the temporal gap process reducing to a modulation depth of around 13 dB. Figure 4.4 shows a 250 ms excerpt of the two resulting modulated noise waveforms.

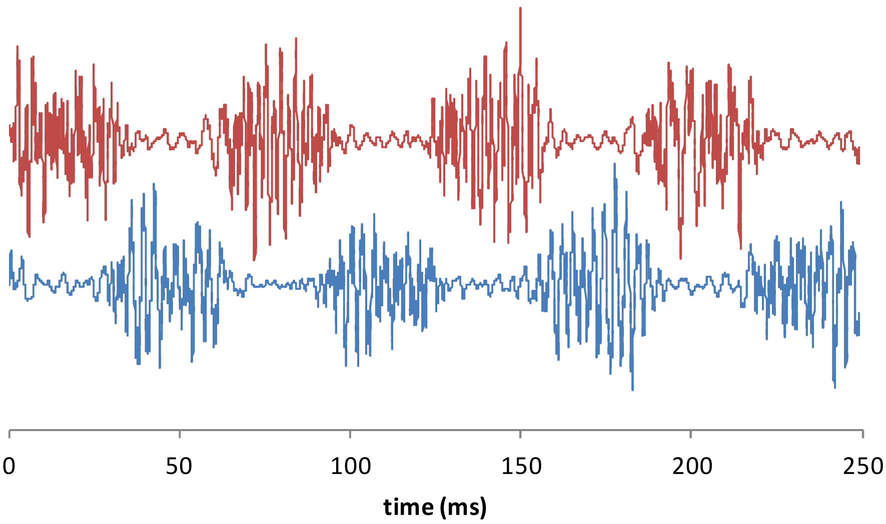

Figure 4.4: A 250 ms excerpt of the two resulting modulated noise waveforms.

While the time-domain representations look similar, the spectral content of the two waveforms differ, as the second waveform was filtered so as to remove the opposite ERB pairs to the first waveform (i.e. ERBs 3, 4, 7, 8, 11, 12… instead of 1, 2, 5, 6, 9, 10…). The spectra of the two filtered waveforms are shown in Figure 4.5.

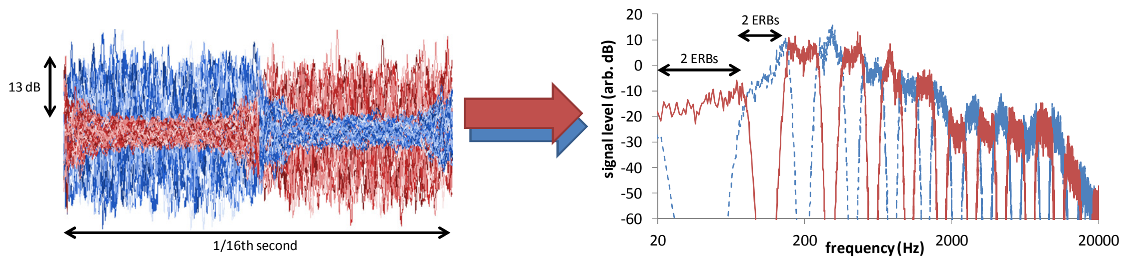

Figure 4.5: The temporal and spectral relationships between the two halves of the STG noise are shown in the left and right panels respectively. The left panel shows 160 superimposed pairs of noise waveforms (each 62.5 ms in duration).

As is clear from Figure 4.5 and Figure 4.6 below, the unique design of STG noise allows for 2-ERB wide spectral gaps (at any given point in time) and 16 Hz temporal gaps (at any given frequency). The STG noise was adjusted to have the same long-term level as the unmodulated speech noise and was added to the digit material in exactly the same way as that noise.

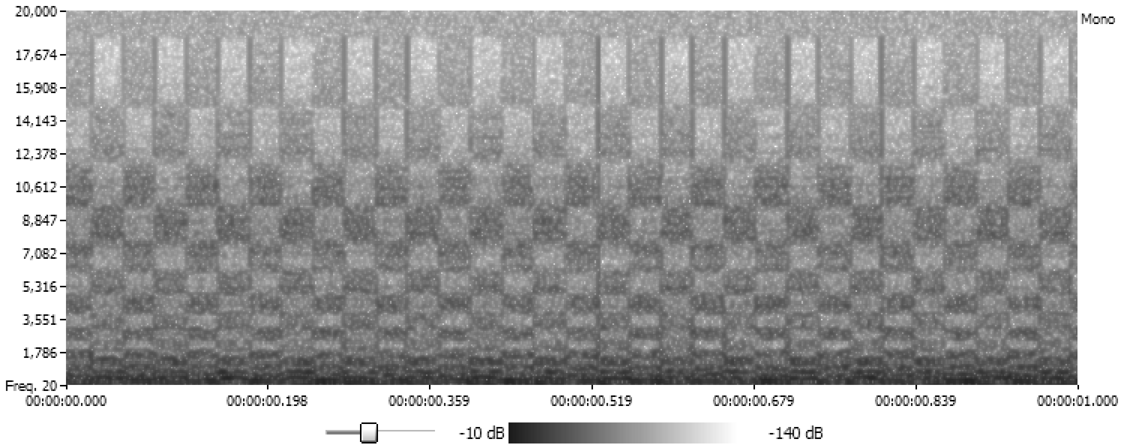

Figure 4.6: A spectrogram of a one second excerpt of STG noise (512 point FFT, 99% overlap, Blackman-Harris window).

4.1.4. Interview Procedure

The interview was undertaken in the Resound Booth 2 at the University of Canterbury (mean background sound level 29.4 dB A) in January 2013. Each participant was tested individually at scheduled appointments arranged via email. The appointment began with an unstructured interview where the procedure was explained to the participant and they were asked to sign a consent form with the understanding that their test results would be de-identified and would be destroyed after 5 years. They were also given the opportunity to enter a prize draw to win one of six Westfield Mall vouchers to the value of sixty dollars.

Otoscopy was performed to assess the health of the external auditory canal and tympanic membrane, and to ensure that if cerumen was present it would not interfere with audiometric testing.

4.1.5. Digit Triplet Test Procedure

Participants were seated at a laptop connected to a telephone for the DTT. The DTT software was open on the desktop, so the participant could view each of their responses before pressing enter (Figure 4.7). The participants were told they were to hold the telephone handset to their ear to hear the digit stimuli and that the 168 triplet stimuli would be played four times during the test; one with the continuous speech noise played to the (i) left ear, and once to the (ii) right, and one with the STG noise played to the (iii) left ear and (iv) right ear. The order of the presentations was alternated by the researcher to reduce the likelihood of a learning effect across the participant data (Table 4.2).

Figure 4.7: The computer interface for the normalisation of the telephone New Zealand English DTT.

Table 4.2: Presentation order of the triplet trials for the first four participants; 1= continuous speech noise, 2= STG noise, L=left, R= right.

Participant	First Trial	Second Trial	Third Trial	Fourth Trial
1	1 R	1 L	2 R	2 L
2	2 R	1 R	1 L	2 L
3	1 L	2 L	1 R	2 R
4	2 L	2 R	1 L	1 R

The participants were told that the DTT was trying to find the level at which speech was only just perceptible, and were reassured to not be concerned if the digits became increasingly inaudible; they were instructed to just enter what they thought they heard, or if they had no idea then enter any digit into the number pad and press enter. Participants were not informed that the digits 7 and 0 were omitted, but were told that 0-9 were possible response options.

On completion of each trial the software generated a tab-delimited text file containing their responses for each of the 168 triplets. The participant was thanked for their time at the end of the fourth trial, but no feedback was given on the test results.

4.2 Normalisation Results

Preliminary testing on two participants showed consistently high scores for the digits 3 and 4 in each position which likely to prevent accurate assessment of the mid-points of their psychometric functions. The sound level of these two digits in each position was therefore lowered by 3 dB prior to further testing with the larger group of participants. This modification was taken into account when plotting the data, and the psychometric functions for these two digits (in Figures 4.8 and 4.9) are accurate.

As trials using the STG noise on these two participants showed that all the psychometric functions were shifted to the right by approximately 3 dB, the software was modified to present the stimuli in STG noise at SNRs that were 3 dB worse than for the constant noise so that the mid-points of their functions were central to the tested range.

4.2.1. AUDIOMETRIC RESULTS OF NORMALISATION PARTICIPANTS

Although the audiometric data was not gathered immediately prior to the normalisation assessment, the individuals had audiometric results that were less than 6 months old. All individuals had normal hearing, where normal hearing is defined as having air conduction pure tone thresholds of ≤ 20 dB HL for each of the six audiometric octave frequencies (0.25 - 8 kHz) in each ear (Figure 4.8). The characteristics of the normalisation group are as follows: 7 females (Mean age = 24.6 years, SD ± 4.0 years, PTA M = 2.3 dB HL, SD ± 2.5 dB HL), and 3 males (Mean age = 29.0 years, SD ± 9.2 years, PTA M = -1.9 dB HL, SD ± 2.5 dB HL).

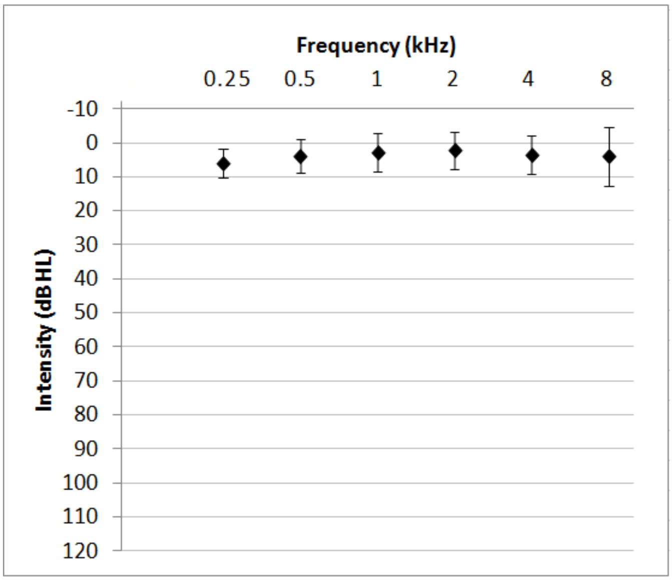

Figure 4.8: Average air-conduction pure tone thresholds (0.25-8 kHz) for the normalisation participants.

By comparison, King (2011) analysed the normalisation data of 22 normal hearing participants (16 female, 6 male, mean age 33.0 years) for the New Zealand English digits of the internet version, and Murray (2012) had 8 participants (5 female, 3 male; mean age 22.8 years) complete her normalisation of the Te Reo Māori digits for the internet version.

4.2.2. Analysis of the DTT with Continuous Speech Noise

As the digits had already been normalised for the broadband version of the test, the psychometric functions obtained using the telephone handset indicated the degree to which a particular digit was either more intelligible or less intelligible in noise when presented over the telephone, either due to the restricted bandwidth or the compression used in the telephone system.

There was substantial variation in the digit psychometric functions for the first stage of the normalisation procedure. The digits embedded in continuous speech noise were not equally intelligible for the participants. Digit number 4 was consistently the hardest to perceive over the telephone, with the midpoint level of the psychometric function (L_{mid}) at -4.5 dB SNR for position 1, -5.4 dB SNR for position 2 and -6.8 dB SNR for position 3. Conversely digit number 8 was the easiest to perceive over the telephone, with L_{mid} points at -9.6 dB SNR, -11.5 dB SNR and, -12.6 dB SNR for positions 1 to 3, respectively. The digit 4 has unvoiced high frequency components in the letter 'f' that are beyond the nominal 3 kHz filter limit of the telephone, compared to the digit 8, which has vowel components (æ) that are not compromised by the telephone bandwidth (Figure 4.9).

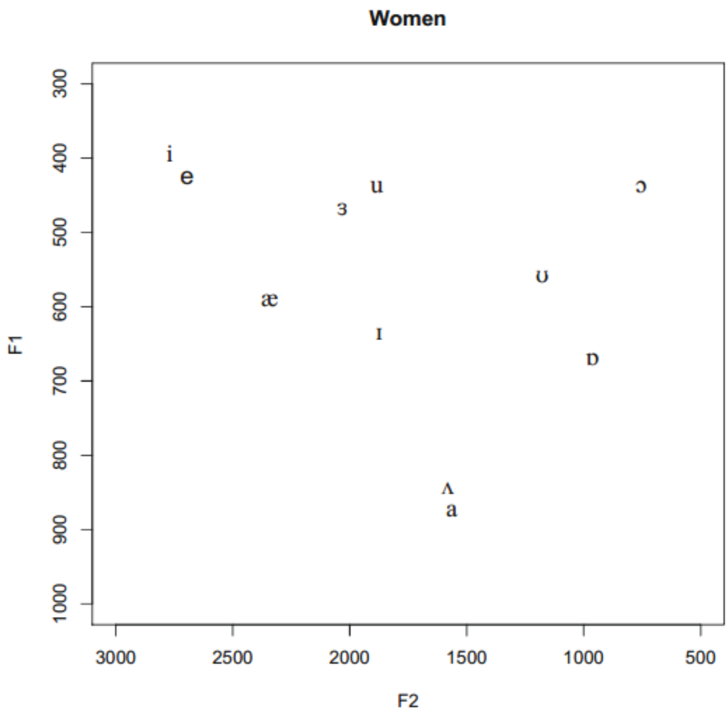

Figure 4.9: Average vowel spaces for forty New Zealand women (Maclagan & Hay, 2004).

Amplitude corrections were then applied to bring the mean psychometric midpoint of all the digits at all three positions in continuous noise to an L_{mid} of -8.9 dB SNR (SD = 1.4 dB). The resulting hypothetical psychometric functions are shown in panel (b) of Figure 4.10. This correction was carried out so that all digits would have a 50% chance of detection when presented at -8.9 dB SNR.

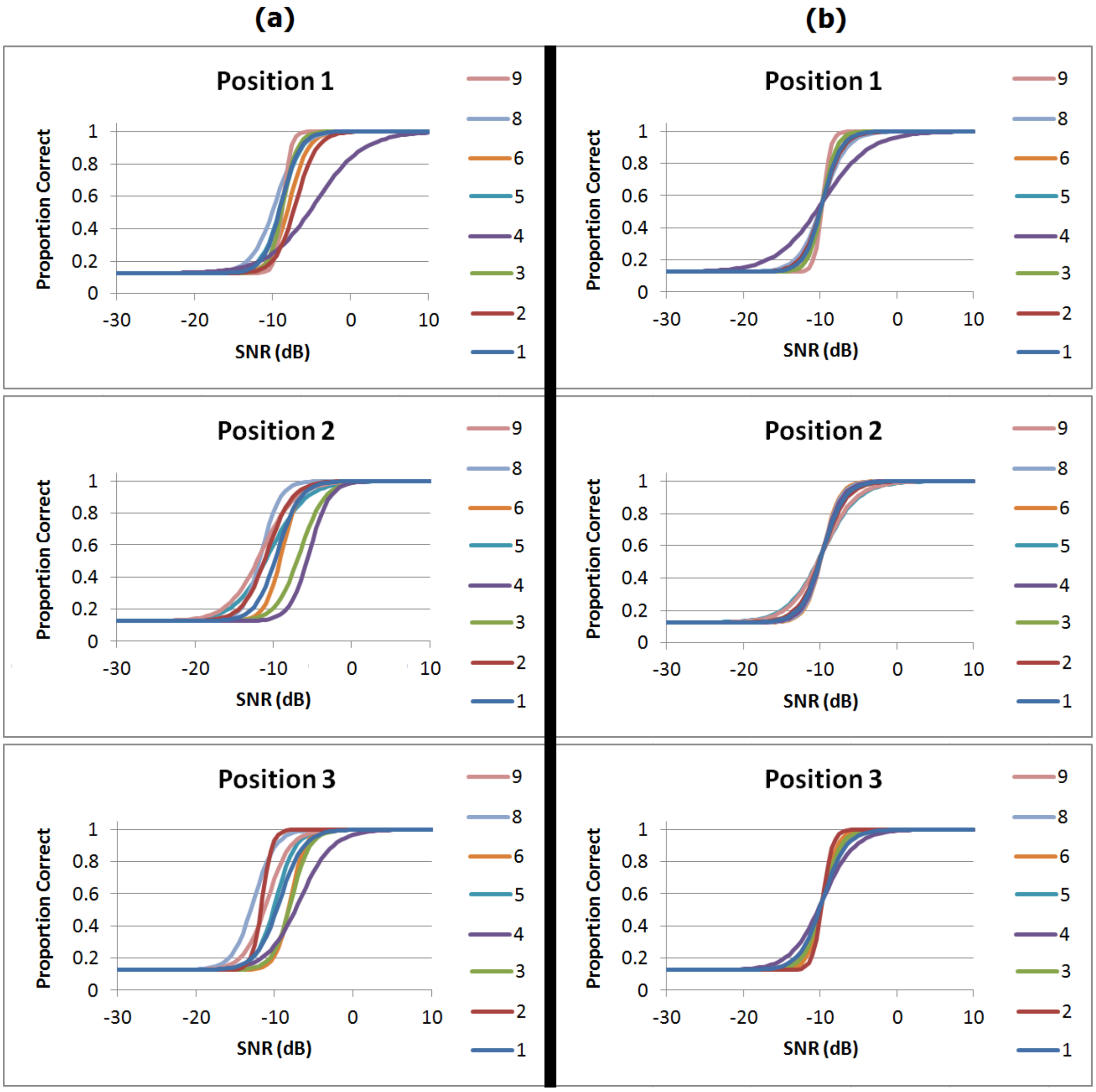

Figure 4.10: The psychometric functions of each digit in the three triplet positions, where continuous speech noise was the masker. Panel (a) displays the psychometric functions relative to the broadband normalised digits of King (2011). Panel (b) displayed the hypothetical psychometric functions after level correction of each digit, to achieve a consistent L_{mid}.

4.2.3. Analysis of the DTT with STG Speech noise

There was slightly less variation in the psychometric functions for digits in STG noise, in the first stage of the normalisation procedure (Figure 4.11a). The digits embedded in STG noise were not equally intelligible when presented over the telephone at any given SNR. Digit 4 remained the number with the largest SNR required for 50% probability of detection (an average L_{mid} = -8.8 SNR across the three positions) and the shallowest slope (average slope at midpoint 10.5%/dB across the three positions). Conversely digit number 2 had the smallest average L_{mid} (-12.9 dB) across the three positions. The digit 2 may have been more audible due to its prominent vowel sound (*u*) which has formant frequencies well within the 3 kHz limit of the telephone bandwidth (Figure 4.9).

Amplitude corrections were then applied to bring the mean psychometric midpoint of all the digits at all three positions in STG noise to an L_{mid} of -11.5 dB SNR (SD = 1.6 dB). The resulting hypothetical psychometric functions are shown in panel (b) of Figure 4.11. This correction was carried out so that all digits would have a 50% chance of detection when presented at -11.5 dB SNR.

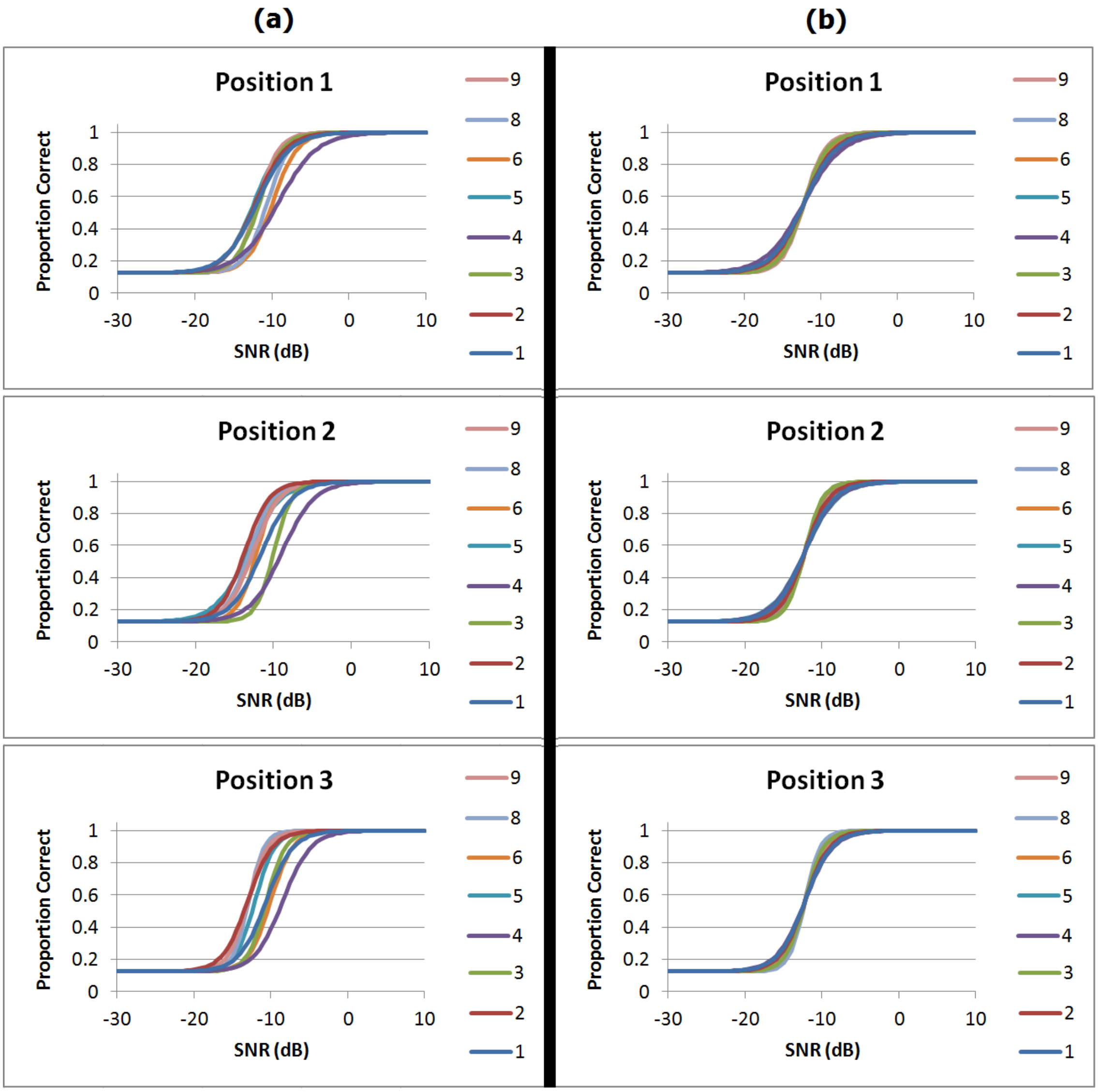

Figure 4.11: The psychometric functions of each digit in the three triplet positions, where STG speech noise was the masker. Panel (a) displays the psychometric functions relative to the broadband normalised digits of King (2011). Panel (b) displayed the hypothetical psychometric functions after level adjustment of each digit, to achieve a consistent L_{mid}.

4.2.4. SUMMARY

In conclusion, it was easier for the participants to detect the digit-triplets when they were masked by the STG noise rather than the continuous noise. The likely cause of this is the normal hearing participants were able to take advantage of the masking-release phenomenon, whereby the fine temporal and spectral resolution of the normal hearing cochlea is able to utilise the small 'glimpses' of the signal within the STG noise to obtain enough information to correctly identify the digits presented (Hewitt, 2008; Wagener & Brand, 2005). In order to determine whether people with hearing loss find digit detection more difficult with a STG noise than a continuous noise, a pilot study for the telephone version of the NZHST which utilises both noise types should be undertaken.

Although the digits were easier to detect in STG noise, the average slope of the psychometric function for the STG noise condition was shallower (14.1%/ dB) than the constant noise (17.9%/ dB) (Figure 4.12). However, the between-digit slope variability in the STG noise was less than half that of the constant noise (a standard deviation of 3.1%/dB for STG noise vs 7.6%/dB for the constant noise), meaning that the sensitivity of individual digits in STG noise was more homogenous. The reduced overall slope for the STG noise is similar to that noted in other speech-in-noise studies that have used fluctuating noise and a continuous noise (Wagener & Brand, 2005).

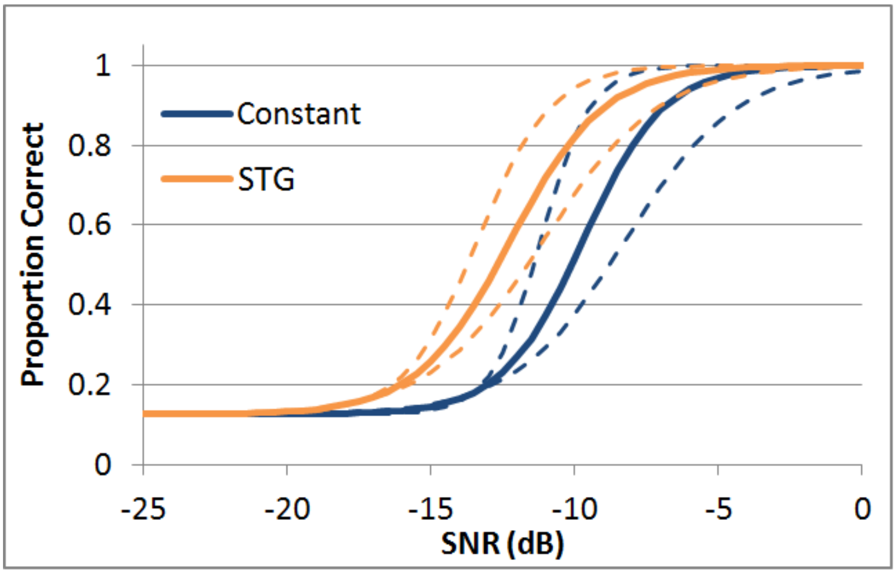

Figure 4.12: The mean psychometric functions (- - - 1 SD) for the digits embedded in the constant noise and STG noise.

Chapter 5 DISCUSSION

5.1 HEARING LOSS AND SPEECH-IN-NOISE

Although the most common complaint of those with hearing loss is the inability to hear speech in noisy situations, this phenomenon is seldom evaluated in audiological assessment (Wilson, Burks, & Weakley, 2006). Speech in noise tests such as the Hearing in Noise Test (HINT) (Nilsson, Soli, & Sullivan, 1994) and the Quick Speech-in-Noise test (QuickSIN) (Killion, et al., 2004) have been developed, but are not widely used in the clinical setting; disregarded in favour of monosyllabic words presented in quiet. McArdle, Wilson, & Burks (2005) note that although pure-tone audiograms and speech-recognition scores in quiet are valuable measures of hearing impairment, they do not quantify the difficulty that the individual has in understanding speech in background noise. The distinction between audiometric testing in quiet and speech-in-noise testing is related to sensitivity and clarity (Killion & Niquette, 2000). The pure-tone audiogram is a measure of hearing sensitivity; a loss of which can be rectified by appropriate amplification. Conversely, a loss of clarity experienced in environments of poor signal-noise-ratio (SNR) cannot be entirely corrected by amplification (Killion & Niquette, 2000).

Speech in noise tests are a quick ecological measure of communication disability (Wilson, McArdle, & Smith, 2007), and as such are a good test for screening for hearing loss. This is because researchers have found that digit, word and sentence materials presented in noise generate a separation of around 8-12 dB SNR between the recognition scores of those with normal hearing and those with hearing impairment (McArdle, et al., 2005). Due to this substantial separation, these tests are ideal for remote use by those requiring a hearing check. Hearing screening tests such as the one used in this research are best aimed at those with thresholds of at least 35 dB HL as they are more likely to seek rehabilitative intervention, than those with a slight hearing loss (Davis, Smith, Ferguson, Stephens, & Gianopoulos, 2007).

5.1.1. PERFORMANCE OF NZ ENGLISH DTT FOR INTERNET

Participants in the verification study who had a mild high frequency hearing loss (in one or both ears) that was concealed by their PTA did not pass the DTT. This type of hearing loss is often overlooked by some audiologists, who believe that good low frequency hearing and a mild loss between 4-8 kHz will have minimal impact on hearing. The findings of this research are contrary to this belief and instead support the view of Killion & Niquette (2000), that to reliably predict an individual's ability to hear in background noise, one must measure it.

There was only one participant with a PTA >20 dB HL that passed the DTT. She had a binaural PTA of 29 dB HL and passed the DTT with a score of −10.4 dB SNR. Factors that may have contributed to her low DTT score included that her sensorineural loss was mild and flat across all frequencies and she was young (25 years). McArdle, et al., (2005) report that PTA is not always a good predictor of word recognition performance in noise. This is because decreased hearing ability can be due to both attenuation (sensitivity) and distortion (clarity), and distortion is not measured via PTA. Furthermore, factors like age and attention to the task can also influence the ability of an individual to obtain a successful result (da Costa & Zimmer, 2012).

In her research, King (2011) grouped the participants into 'normal', 'insufficient' and 'poor' hearing categories, based on their DTT score. The software used in this verification study was created on the basis of the pilot study conducted by King (2011), and thus the verification participants were assigned one of these labels at the end of their test. However, during the analysis of the verification data it was decided to join the 'insufficient' and 'poor' categories into one group called 'hearing loss'. This is because the DTT is a screening tool, which should fundamentally generate a pass or fail result; it is the work of a diagnostic test to assign a level of severity to a given hearing loss. Consequently, when this DTT is released to the public as part of the NZHST, there will only be two possible outcomes for the test result which is displayed by the software: 'normal hearing' or 'probable hearing loss'.

The online software for the verification randomly selected one of the eight digit-triplet lists for each participant (Figure 2.6). As such, analysis could not be undertaken on DTT score trends across the different lists. It would have been more useful to have the software present the lists in a consecutive looped order, so that there were equal presentations of each list.

There was also a substantial difference between the stimulus presentation for the New Zealand English pilot study (King, 2011), and the verification. Participants in the pilot study listened to the binaural digit triplets under earphones, while the verification participants listened to the binaural digit triplets in the sound field. This meant that the results of the verification were not directly comparable to the pilot study. The ideal testing transducers are earphones, so that separate ear information can be gathered. If earphones are not available to an individual doing the NZ English version for internet, then separate ear information is not possible; but sound field presentation through the computer's speakers would allow for at least a binaural screen. It was a change in method that was undertaken because not all individuals taking the test at home would have access to earphones to connect to their computer. In essence the binaural data of the verification has greater face validity than the bilateral data of the pilot study.

The verification participant scores for the binaural DTT were also compared to the self-evaluation of their own hearing ability (Figure 2.10). Individuals with elevated audiometric thresholds tended to rate their hearing ability more poorly than those with audiometric thresholds in the normal range. Likewise, those participants with DTT scores close to 0 dB SNR were more likely to rate their hearing ability at either 1 or 2 out of 5, compared to those with DTT scores close to -10 dB SNR who generally rated their hearing ability at 4 or 5 out of 5. The linear regression carried out on these relationships suggest that this DTT has good face validity for identifying people who believe they have a hearing impairment, and that performance in speech and noise is a good predictor of hearing ability.

Analysis of the separate ear DTT results for the verification participants resulted in a 90% sensitivity and 88% specificity for correctly identifying those with hearing loss when the cut-off SNR for normal hearing was set at -10.0 dB SNR.

Analysis of the participant demographics revealed that there was a correlation (r value = 0.53) between age and binaural PTA, with older individuals being more likely to have elevated PTAs (Figure 2.11).

5.1.2. Performance of Te Reo Maori DTT for Internet

This pilot study was restricted by the number of participants recruited. It was difficult to find individuals willing to participate who considered themselves reasonably familiar with Te Reo Māori. In particular, there was a lack of Te Reo speaking participants with hearing loss. This meant that the correlations performed in Figures 3.2 and 3.6 have to be interpreted with caution. Murray (2012) noted in her research that when only a small numbers of individuals participate in a DTT study, lapses in concentration or guesses made by these participants can have a significant impact on the mean results.

As well as a general lack of participants for the Te Reo Māori version there was also an age and gender imbalance in the participants that were tested. Twenty-one of the 27 participants were female and only seven of the 27 individuals were over 45 years of age. Consequently, only four individuals had a binaural PTA threshold that revealed a hearing impairment, and all of these individuals were female. As these women had binaural PTAs over 25 dB HL, unsurprisingly the DTT was able to correctly identify all four of them as hearing impaired, and the remaining individuals (with binaural PTAs less than 20 dB HL) as normal hearing when the SNR cut-off for normal hearing was -6.8 dB SNR. Thus, the binaural DTT pilot study had both a sensitivity and specificity of 100%. Again, these figures must be treated with caution given the low participant numbers.

In the separate ear testing, data was gathered from 54 ears; 43 ears had normal PTA, while 11 had elevated PTAs. When the SNR cut-off for normal hearing was placed at -2.8 dB SNR, eight of the 11 individuals with hearing impairment were correctly identified. This caused DTT test sensitivity to be 72.7% and specificity to be 100%. The three remaining ears belonged to individuals who were aged 21 and 28 with mild or moderate losses at selected frequencies. It is possible that although these individuals had some deficits in peripheral hearing, their youth meant that cognitive processes such as working memory, inhibitory control and processing speed resulted in DTT scores as good as normal hearing participants (Van der Linden et al., 1999).

In her research, Murray (2012) also found it challenging to find speakers of Te Reo Māori over the age of 18 with either normal hearing or hearing loss in the Christchurch region. In order to ensure that future research for the Te Reo version of the NZHST has access to a substantial pool of speakers of Te Reo Māori, it may be prudent to attempt data collection for the verification of this pilot study in the North Island, where there are a greater number of individuals who are confident conversers in Te Reo Māori.

The hearing self-evaluation revealed that individuals who view their hearing as poor (1-2 out of 5) were more likely to have an elevated binaural PTA (r value = 0.45). There was a stronger correlation between the age of participants and their binaural PTA (r value = 0.52), where older individuals were more likely to have an elevated binaural PTA. A very weak correlation (r value = 0.05) was found between binaural DTT score and familiarity with the digits of Te Reo, suggesting that as long as there was a rudimentary understanding of the Te Reo digits, an individual's scores were not predicted by their confidence with Te Reo Māori.

The researcher aimed to have an equal number of presentations for each of the eight DTT lists in each of the three conditions (right, left, binaural) (Table 3.4). This was made possible through rotating the presentation of the eight different DTT lists, so that participant one would hear lists 1, 2 and 3; participant two would hear lists 4, 5 and 6 and so on. Ideally this systematic list presentation would reduce any "list effect" whereby a certain list or lists were easier or harder to detect than others, or would make any such effect easy to identify. Furthermore, by rotating the order in which lists were presented in the three conditions, any potential "learning effect" would be reduced. More plainly, if every participant had the right ear as the first condition, then it is possible that data analysis would reveal that the right ear performance was poorer overall for the entire sample than the left or binaural condition.

5.1.3. Normalisation of the NZ English DTT for Telephone

In many of the established DTT tests for different European languages the masking noise utilised is a continuous speech noise created by thousands of superimpositions of the speech material (Zokoll, et al., 2012). This creates an optimal masker because the long term speech spectrum of the noise fits within the spectrum of the speech signal (Kollmeier, 1990). However, successive studies have found that temporal and spectral modulation of the noise can help better differentiate between listeners with normal hearing and those with hearing loss (George, et al., 2006; Peters, et al., 1998; Wilson, et al., 2010). In this research the recommendation of Smits & Houtgast (2007) was upheld by using an interrupted noise with temporal gaps of 16 Hz for use over the telephone, which they had deemed suitable for hearing screening purposes. King (2011) had also recommended that interrupted noise could be utilised in further development of the NZHST.

A spectral-temporal gap (STG) noise was created using temporal gaps of 16 Hz (Smits & Houtgast, 2007), and spectral gaps that were two equivalent rectangular bandwidths wide according to the formula of Glasberg & Moore (1990). This STG noise and a continuous noise were used as maskers for the normalisation of the New Zealand English DTT for telephone. All of the normalisation participants listened to both types of noise with each ear.

According to the results of the normalisation, the digits were easier for the normal hearing listeners to detect when embedded within an STG noise (L_{mid} = -11.5 dB SNR, SD = 1.6 dB), rather than a continuous noise (L_{mid} = -8.9 dB SNR, SD = 1.4 dB). However the slope of the psychometric curve was shallower for the STG noise (14.1%/ dB) than the continuous noise (17.1%/ dB). These results are consistent with the findings of Wagener and Brand (2005) and Hewitt (2008). However, the standard deviations for the average L_{mid} point of the two noise conditions are more closely aligned in this research than in that of Wagener and Brand (2005). In their research, the SRT for the modulated noise condition had a standard deviation that was double (SD = 3.0) that of the continuous noise (SD = 1.3). This large amount of variation may have been reduced in the current research by a more controlled formation of the fluctuating noise with a specific rate of temporal (16 Hz) and spectral (two equivalent rectangular bandwidths) modulation. Trials of STG noise with hearing impaired listeners need to be performed before its suitability for a screening test can be determined.

5.2 Internet and Telephone DTTs

The difference between the two transducers used in this study largely relate to whether test is undertaken in a binaural or separate ear method. When the NZHST is released to the public, the individuals taking the test will have the option of using (a) the internet or (b) the telephone. If the internet is chosen, individuals who own a set of earphones can utilise them to obtain separate ear information, this is the most ideal form of screening because it assess the hearing ability of each ear. If earphones are not available, the test can be undertaken using the computer speakers. This will give a binaural result, which will essentially be testing the abilities of the better ear. Ambient noise in the room where the test is taken may also have an influence on the DTT results. If the telephone is the chosen transducer then separate ear information can be gathered but no binaural data is possible. There are also limitations to consider when using the telephone as a transducer for the DTT. The main one being that a telephone uses frequency-limiting in sound transmission, so there are some high speech frequencies that are not tested by a telephone DTT (Jansen, et al., 2010). Another limitation is that the influence of ambient noise in the home test environment cannot be controlled, and thus the DTT scores of those undertaking the telephone test are likely to have more elevated SNRs than those who used earphones for the internet version.

Although undertaking the internet DTT with earphones has the benefit of yielding separate ear information, the binaural sound-field speaker method had better real world validity. That is because, for most people, two ears are used in challenging communication situations to help enhance speech detection in noise. The advantages of binaural hearing over monaural hearing in background noise have been long recognised (Hirsh, 1948; Keys, 1947). Nonetheless, by testing in a binaural setting in the soundfield or under earphones, the screening test is really only assessing the abilities of the better ear.

There are substantial differences in DTT scores and cut-off values for normal hearing between the two languages. Even the normal hearing listeners from each language had a large variation in score. Murray (2012), concluded that direct comparisons between different tests presented in New Zealand English and Te Reo Māori would bring forth issues surrounding validity of cross-language analysis. However, it is interesting to at least note the differences yielded by each DTT study. In the New Zealand English DTT study the binaural test (transduced via laptop speakers) had the cut-off for normal hearing at -8.8 dB SNR and the separate ear test (transduced via earphones) had a cut-off at -10.0 dB SNR. The difference between the two transducers used may have contributed to the difference in the cut-off values, through the ambient noise of the sound treated room (mean ambient sound level 29.5 dB A) in the binaural condition meaning a better signal to noise ratio was required for the participants to score as well. In the Te Reo Māori DTT, the binaural cut-off value was -6.8 dB SNR while the separate ear cut off was -2.8 dB SNR. Both the binaural and separate ear conditions were presented under earphones in the same manner as the pilot study for the New Zealand English conducted by King (2011). In this instance the signal input from both the left and right in the binaural condition (which in reality is actually bilateral not binaural) improved the ability to detect the digit triplets and therefore the SNR was poorer than in the separate ear condition where there was only unilateral signal input.

5.3 Limitations of this research

As a screening tool, the DTT presented via telephone or internet has certain limitations. In her research King (2011) noted that like other remote screening tests, the DTT does not determine site of lesion, and nor can the home environment be controlled to ensure the best testing conditions. Other researchers have noted that the DTT should be viewed as a test of “hearing disability”, not to be confused with or assumed to be a replacement for the gold standard of diagnostic audiology, pure-tone audiometry, which is a test of “hearing impairment” (Smits & Houtgast, 2005). The DTT is best used as a remote hearing screening test, because in clinical settings a sentence-in-noise test would be more appropriate. The length of the stimuli in the DTT is sufficient for screening, but for a more thorough assessment of hearing ability in background noise, a sentence-length test would have greater face validity (Zokoll, et al., 2012).

For this research in particular, the delay in acquiring approval from the University of Canterbury Human Ethics Committee meant that participant recruitment did not commence before June 2012. Volunteers were sought first for the Te Reo Māori pilot study, because of the small population of confident Te Reo conversers, and then for the New Zealand English speakers for the verification and the normalisation trials.

Murray (2012) also experienced difficulty in recruiting sufficient participants in the Christchurch area for the Te Reo Māori version. In her recommendations she noted that Māori prefer face-to-face interaction when being asked to participate in research, and that advertising posters alone were not sufficient to encourage potential Māori participants (King, Maclagan, Harlow, Keegan, & Watson, 2011). With this advice, informative presentations about the research project were given to kapa haka groups and to those attending a community health expo. However, the final number of individuals who participated in the Te Reo Māori pilot study was too small to draw reliable conclusions from the data gathered. Of the individuals that did volunteer, many were not as confident with Te Reo Māori digits as hoped, so it is possible that this may have affected the data analysis. Any further formation of this version of the NZHST would benefit from North Island data collection, where there is a greater population of those who regularly converse in Te Reo Māori.

Chapter 6 CONCLUSION

6.1 VALUE OF THE NEW ZEALAND HEARING SCREENING TEST

Despite being one of the most common chronic conditions to affect adults, hearing loss is largely under-diagnosed in most populations. Health professionals agree that there is a need to decrease the level of under-diagnosis, in order to encourage individuals to prioritise their ability to communicate, so quality of life can be preserved in the aging process (Jansen, et al., 2010).

For many people who suspect they have a hearing loss, visiting a hearing professional is too big a first step (Koopman, Davey, Thomas, Wittkop, & Verschuure, 2008). An easily accessible screening test, which can be undertaken independently and remotely, could be a more acceptable initial starting point. Pure-tone audiometry would not be suitable for home-based, independent testing as the acoustics and ambient noise of the home environment would be uncontrolled. Questionnaires such as the HHIE-S (Hearing Handicap Inventory for the Elderly – Screening version) have adequate sensitivity and specificity for predicting a hearing loss, but such testing is subjective (Koopman, et al., 2008). Remote speech-in-noise tests have become a favoured form of remote hearing screening for two reasons. Firstly, one of the biggest complaints expressed by those with hearing loss is a decreased ability to hear in background noise, thus there is face validity in screening with a speech-in-noise test. Secondly, due to the speech and noise having the same frequency envelope, these tests are relatively independent of presentation level (Smits & Houtgast, 2005).

Speech-in-noise tests have been largely presented to the public via two popular mediums; the landline telephone and the internet. When the Dutch DTT was released to the public 65,924 people took the test within the first four months (Smits & Houtgast, 2005). Likewise the French DTT was used by 15,000 people in its first month of release (Jansen, et al., 2010). The success of these tests in other nations has led to the formation of the NZHST, a DTT available to the New Zealand public in the country's two official spoken languages and accessible by landline telephone or internet. This remote hearing screening test aims to reach those who are in rural areas or who may find either physical, financial or psychological barriers to attend an audiological clinic (Jansen, et al., 2010). The internet version of the test is predicted to become more important as broadband access becomes more universal and as an increasing percentage of baby boomers (who are using the internet in their latter decades in the workforce) begin to be affected by presbycusis (Koopman, et al., 2008). Similarly, a need may soon arrive for a cellular phone version as more and more households decide not to have a landline telephone (Koopman, et al., 2008).

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APPENDICES

Appendix 1: Confirmation of Enrolment letter from the College of Science.

College of Science

Isobel Phillips, Academic Manager

Tel: +64 3 364 2987 ext: 3127. Fax +64 3 364 2490

Email: isobel.phillips@canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

26th March 2012

alice.bowden@pg.canterbury.ac.nz

Student Number: 79380700

Dear Alice,

Congratulations on your enrolment in a Master's thesis.

Your official thesis start date is 1st March 2012. Your thesis submission dates are as follows:

With eligibility for Honours: 28th February 2013. Without eligibility for Honours: 28th February 2013

Your next milestone is the submission of your research proposal and registration form, which is due 2 months after your thesis start date, if enrolled full-time, and 4 months after the commencement date, if enrolled part-time. This application is initiated by you and completed with your supervisor. Your Department/School submits this form to the College for approval. This form is available on: http://www.canterbury.ac.nz/postgrad/masters/maproposal.shtml

Please take the time to check out your College Postgraduate website for further information, including progress report requirements, suspensions, and extensions. The information contained within these websites is important for you to know.

If the time limit for your thesis is greater than 12 months you will be required to re-enrol before your enrolment expires. The College will email you and advise that you need to re-enrol.

There are a number of places you can go for advice and support as needed, College Office for academic advice, Student Support Services (http://www.canterbury.ac.nz/support/), the Learning Skills Centre (http://www.lps.canterbury.ac.nz/lsc/), and the University Health Centre (http://www.canterbury.ac.nz/healthcentre/).

This letter is important for you to keep on file as it provides you with your original thesis start date and submission dates. This information will also be on the student web and as a note at the end of your academic record. If you have a questions do not hesitate to contact the College Office.

Best wishes with your research.

Yours sincerely

Isobel Phillips

Academic Manager

Appendix 2: Approval from the University of Canterbury Human Ethics Committee.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2012/43

13 June 2012

Alice Bowden
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Alice

The Human Ethics Committee advises that your research proposal "Development, normalisation and verification of the New Zealand hearing screening test for Maori and New Zealand English" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 8 June 2012.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

Appendix 3: Approval from the University of Canterbury Māori Research Advisory Group.

Māori Research Advisory Group

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Tel: +64 3 364 3050 Fax: + 64 364 2950
Email: john.pirker@canterbury.ac.nz

Friday 18 May 2012

Tenā koe Alice,

Re: Development and Verification of the New Zealand Hearing Screening Test for Maori and New Zealand English

Ngā mihi ō te wā ki a koe, te kairangahau ō tenei kaupapa whakahirahira. Ngā mihi hoki ki a koe i runga i tenei te whakawhitiwhiti korero ki te whakapakari te mahi.

Thank you for your consultation form. The Māori Research Advisory Group (MRAG) is happy to support your research. We appreciate the on-going efforts of your research to develop a Māori language component for the New Zealand Hearing Screening Test. We also acknowledge that your work may provide for greater acessability for such tests by using the phone or internet. In the long term, we hope that your research will result in the early identification and reduction of hearing deficiencies in Māori. We wish you all the best in your research and look forward to seeing a summary of the results once your research has been completed.

Nāku noa (Yours sincerely)

Dr John Pirker
Māori Research Advisory Group
University of Canterbury

Appendix 4: Approval for two month extension of submission date.

College of Science

Tel: +64 3 364 2312, Fax: +64 3 364 2490
collegeofscience@canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

4th March 2013

alice.bowden@pg.canterbury.ac.nz

Alice Bowden
172 King Street
Cambridge
Waipa 3434

Dear Alice,

I write in reply to your application.

I am pleased to inform you that the Academic Manager of the College of Science has resolved:

> That the application for **Alice Therese BOWDEN** to be granted a two month academic extension to her MSc thesis from 28th February 2013, with a new submission date of 29th April 2013 with or without eligibility for honours, has been approved.

Because you are required to be an enrolled student at the date of submission, an extension of time for submission may require you to re-enrol and pay additional fees. You should, therefore, discuss fees implications with Student Administrative Services (Student Services Centre).

If you are on a student allowance or loan, there are financial implications; therefore, you should discuss these with StudyLink.

The submission date of your thesis is shown as a note on the bottom of your academic record, which you can access via the student web-site.

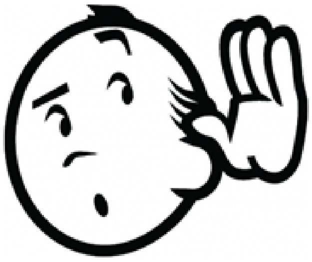
Yours sincerely

Isobel S Phillips
Academic Manager
(College of Science)

cc Student Administration
HOD: Communication Disorders
Resolution: Science
RECORDS: 79380700

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. *www.canterbury.ac.nz*

Appendix 5: Advertisement for normalisation and verification of the New Zealand English version.



Hear, Hear!

Volunteers Needed

for the development of a New Zealand Hearing Screening Test

If you:

- Are 18 years or older
- Have **normal hearing or a hearing loss**
- Have **New Zealand English as your first language**

A service is being developed that needs your help!

We are currently designing a hearing screening test that can be done over the phone or internet. This means it can be used by anyone in the country, no matter where they live. To create a test that will be useful for all New Zealanders, we are making both English and Te Reo versions.

We need people with a variety of hearing ability, from **normal hearing** to those with **hearing loss** in one or both ears.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch throughout 2012. Only one session of about 40 minutes is needed, and during this time you will:

- Get a free hearing check
- Be entered into a prize draw to win one of six $50 Westfield Mall vouchers
- Help us develop a unique and wide-reaching test for communities all over NZ

If you would like more information, or to be involved in this project,
please contact **Alice Bowden** at **atb47@uclive.ac.nz** or text/call **027 340 8586**

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee

Hearing Test
Alice – 027 340 8586
atb47@uclive.ac.nz

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atb47@uclive.ac.nz

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Hearing Test
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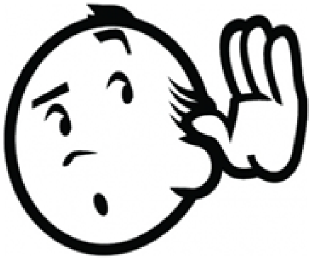
atb47@uclive.ac.nz

Appendix 6: Advertisement for pilot study of the Te Reo version.



Tēnā koutou! Kia ora!

Volunteers Wanted

for the development of a Te Reo Hearing Screening Test

If you:

- Are 18 years or older
- Have **normal hearing or a hearing loss**
- Knowledge of **Te Reo Māori** to a conversational level, including numbers?

A service is being developed that needs your help!

We are currently designing a hearing screening test that can be done over the phone or internet. This means it can be used by anyone in the country, no matter where they live. To create a test that will be useful for all New Zealanders, we are making both English and Te Reo versions.

We need people with a variety of hearing ability, from **normal hearing** to those with **hearing loss** in one or both ears.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch throughout 2012. Only one session of about 40 minutes is needed, and during this time you will:

- Get a free hearing check
- Be entered into a prize draw to win one of six $50 Westfield Mall vouchers
- Help us develop a unique and wide-reaching test for communities all over Aotearoa

If you would like more information, or to be involved in this project, please contact **Alice Bowden** at **atb47@uclive.ac.nz** or text/call **027 340 8586**

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee

Te Reo Hearing Test
Alice – 027 340 8586
atb47@uclive.ac.nz

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Te Reo Hearing Test
Alice – 027 340 8586
atb47@uclive.ac.nz

Version 2.0, 10 May 2012

Appendix 7: Information sheet and consent form for New Zealand English version verification.

Master's of Audiology Programme

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Digit Triplet Test (DTT) Information Sheet

Dear ....,

My name is Alice Bowden and I am a student at the University of Canterbury, undertaking a Master of Audiology Degree in the Department of Communication Disorders.

We are currently designing a hearing screening test that can be done over the phone or the internet. This means it can be used by anyone in the country, no matter where they live. To create a test that will be useful for all New Zealanders, we are making both English and Te Reo versions.

As part of my thesis research I am conducting a verification test of the newly developed New Zealand Hearing Screening Test (NZHST) for speakers of **New Zealand English**. I need people with a variety of hearing ability, from **normal hearing** to those with **hearing loss** in one or both ears.

The Digit Triplet Test (DTT) that participants perform takes about **15 minutes**. The exercise involves listening to three-digit number combinations and entering them into a computer keyboard.

All information gathered during testing will remain confidential and data will be destroyed 5 years after study completion. This project has the approval of the University of Canterbury Human Ethics Committee.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch.

Thank you very much for your time and help in making this research possible. If you have any queries or wish to know more please contact me on 027 340 8586 or at atb47@uclive.ac.nz

My thesis Supervisor is:

Dr Greg O'Beirne
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8140
Tel. (03) 364-2987 ext 7085

The Head of my programme is

Prof Michael Robb
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8140
Tel. (03) 364-2987 ext 7077

Version 2.0 10 May 2012

Consent to Release of Audiological Records and Enter Prize Draw

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Master of Audiology Programme

I agree to let Alice Bowden see my Audiology files. I also agree to take part in a Digit-Triplet Test hearing screening exercise for speakers of New Zealand English. I understand that all the information and test results gathered will be held confidential and destroyed after 5 years.

Signed:..

Participant Name:..*(please print clearly)*

Date:...

Participants in this study can be entered in a **prize draw** to win one of six $50 Westfield Mall vouchers.

If you would like to be enter, please leave contact details so we can reach you if you win.

Email address...

Telephone number..

In my opinion consent was given freely and with understanding.

Signed:...(Masters of Audiology Student)

Student Name:..*(please print clearly)*

Date:...

Version 2.0 10 May 2012

Appendix 8: Information sheet and consent form for Te Reo Māori version pilot study.

Master's of Audiology Programme

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Digit Triplet Test (DTT) Information Sheet

Dear ....,

My name is Alice Bowden and I am a student at the University of Canterbury, undertaking a Master of Audiology Degree in the Department of Communication Disorders.

We are currently designing a hearing screening test that can be done over the phone or the internet. This means it can be used by anyone in the country, no matter where they live. To create a test that will be useful for all New Zealanders, we are making both English and Te Reo versions.

As part of my thesis research I am conducting a pilot study of the newly developed New Zealand Hearing Screening Test (NZHST) for **speakers of Te Reo**. I need people with a variety of hearing ability, from **normal hearing** to those with **hearing loss** in one or both ears.

The Digit Triplet Test (DTT) that participants perform takes about **15 minutes**. The exercise involves listening to three-digit number combinations recorded in Te Reo and entering them into a computer keyboard.

All information gathered during testing will remain confidential and data will be destroyed 5 years after study completion. This project has the approval of the University of Canterbury Human Ethics Committee.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch.

Thank you very much for your time and help in making this research possible. If you have any queries or wish to know more please contact me on 027 340 8586 or at atb47@uclive.ac.nz

My thesis Supervisor is:

Dr Greg O'Beirne
Department of Communication Disorders
University of Canterbury
Private Bag 4800
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The Head of my programme is

Prof Michael Robb
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8140
Tel. (03) 364-2987 ext 7077

Version 2.0 10 May 2012

CONSENT TO RELEASE OF AUDIOLOGICAL RECORDS AND ENTER PRIZE DRAW

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Master of Audiology Programme

I agree to let Alice Bowden see my Audiology files. I also agree to take part in a Digit-Triplet Test hearing screening exercise for speakers of Te Reo. I understand that all the information and test results gathered will be held confidential and destroyed after 5 years.

Signed:..

Participant Name:..*(please print clearly)*

Date:..

Participants in this study can be entered in a **prize draw** to win one of six $50 Westfield Mall vouchers.

If you would like to be enter, please leave contact details so we can reach you if you win.

Email address..

Telephone number..

In my opinion consent was given freely and with understanding.

Signed:..(Masters of Audiology Student)

Student Name:..*(please print clearly)*

Date:..

Version 2.0 10 May 2012

Appendix 9: Information sheet and consent form for New Zealand English normalisation.

Master's of Audiology Programme

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Digit Triplet Test (DTT) Information Sheet

Dear ....,

My name is Alice Bowden and I am a student at the University of Canterbury, undertaking a Master of Audiology Degree in the Department of Communication Disorders.

We are currently designing a hearing screening test that can be done over the phone or the internet. This means it can be used by anyone in the country, no matter where they live. To create a test that will be useful for all New Zealanders, we are making both English and Te Reo versions.

As part of the development of the New Zealand Hearing Screening Test (NZHST) for speakers of **New Zealand English**, I need participants with **normal hearing** to perform a short exercise.

The Digit Triplet Test (DTT) that participants perform takes about **15 minutes**. The exercise involves listening to three-digit number combinations recorded in New Zealand English and entering them into a computer keyboard.

All information gathered during testing will remain confidential and data will be destroyed 5 years after study completion. This project has the approval of the University of Canterbury Human Ethics Committee.

This study will take place at the University of Canterbury Speech & Hearing Clinic, Creyke Road, Ilam, Christchurch.

Thank you very much for your time and help in making this research possible. If you have any queries or wish to know more please contact me on 027 340 8586 or at atb47@uclive.ac.nz

My thesis Supervisor is:

Dr Greg O'Beirne
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The Head of my programme is

Prof Michael Robb
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8140
Tel. (03) 364-2987 ext 7077

Version 2.0 10 May 2012

Consent to Release of Audiological Records and Enter Prize Draw

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Master of Audiology Programme

I agree to let Alice Bowden see my Audiology files. I also agree to take part in a Digit-Triplet Test hearing screening exercise for speakers of New Zealand English. I understand that all the information and test results gathered will be held confidential and destroyed after 5 years.

Signed:..

Participant Name:...*(please print clearly)*

Date:...

Participants in this study can be entered in a **prize draw** to win one of six $50 Westfield Mall vouchers.

If you would like to be enter, please leave contact details so we can reach you if you win.

Email address..

Telephone number...

In my opinion consent was given freely and with understanding.

Signed:..(Masters of Audiology Student)

Student Name:...*(please print clearly)*

Date:...

Version 2.0 10 May2012